

# Building Forest Carbon Projects

## *Carbon Stock Assessment Guidance*



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# Building Forest Carbon Projects

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## Carbon Stock Assessment Guidance

### *Inventory and Monitoring Procedures*

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L&C Carbon

July 2011

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Preferred Citation: Diaz, David, and Matt Delaney. *Carbon Stock Assessment Guidance: Inventory and Monitoring Procedures*. In Building Forest Carbon Projects, Johannes Ebeling and Jacob Olander (eds.). Washington, DC: Forest Trends, 2011.



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## Acknowledgements

This chapter has benefitted from the review and helpful suggestions of Bryan Foster (EcoLogic Development Fund), and Tim Pearson (Winrock International). These contributions are gratefully acknowledged, though all remaining errors of fact or judgment are the sole responsibility of the principal authors.

We also would like to thank Michael Jenkins, Founder and President of Forest Trends, as well as Gena Gammie and Anne Thiel, and the entire Forest Trends staff for their support.

# Building Forest Carbon Projects



2011

This guidance document is part of a Forest Trends series *Building Forest Carbon Projects*. Available at [http://www.forest-trends.org/publications/building\\_forest\\_carbon\\_projects](http://www.forest-trends.org/publications/building_forest_carbon_projects).

Other documents in this series, referred to throughout this document, include:

**Step-by-Step Overview and Guide**

*Jacob Olander and Johannes Ebeling*

**REDD Guidance: Technical Project Design**

*Joerg Seifert-Granzin*

**AR Guidance: Technical Project Design**

*Johannes Ebeling and Alvaro Vallejo*

**Community Engagement Guidance: Good Practice for Forest Carbon Projects**

*Tom Blomley and Michael Richards*

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*Phil Covell*

**Social Impacts Guidance: Key Assessment Issues for Forest Carbon Projects**

*Michael Richards*

**Biodiversity Impacts Guidance: Key Assessment Issues for Forest Carbon Projects**

*John Pilgrim, Jonathan Ekstrom, and Johannes Ebeling*

# Acronyms

AFOLU	Agriculture, Forestry, and Other Land Use
AR	Afforestation and Reforestation; A/R denotes a CDM project category
BEF	Biomass expansion factor
CCB	Climate, Community & Biodiversity [Alliance or Standards]
CDM	Clean Development Mechanism
DBH	Diameter at breast height
GHG	Greenhouse gas
GIS	Geographic Information System
GPS	Global Positioning System
IFM	Improved Forest Management
IPCC	Intergovernmental Panel on Climate Change
LIDAR	Light Detection and Ranging
LULUCF	Land Use, Land-Use Change, and Forestry
P-GIS	Participatory Geographic Information System
QA/QC	Quality assurance and quality control
REDD	Reducing Emissions from Deforestation and Forest Degradation
REDD+	Reducing Emissions from Deforestation and Forest Degradation, conservation of forest carbon stocks, sustainable management of forests, and enhancement of forest carbon stocks
SOP	Standard operating procedure
VCS	Verified Carbon Standard
AFOLU	Agriculture, Forestry, and Other Land Use
AR	Afforestation and Reforestation; A/R denotes a CDM project category
BEF	Biomass expansion factor
CCB	Climate, Community & Biodiversity [Alliance or Standards]
CDM	Clean Development Mechanism
DBH	Diameter at breast height
GHG	Greenhouse gas
GIS	Geographic Information System

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# Introduction

Procedures for designing and completing a forest carbon inventory have generally received more attention than other aspects of project development, and detailed technical guidance exists regarding many aspects. The extensive body of experience with traditional timber inventory methods as well as ecological biomass surveys has allowed for forest carbon inventory approaches to be developed through relatively minor adjustments to existing methods.

Despite the relatively well-established technical documentation for conducting forest carbon inventories, strategic guidance on unique and evolving considerations for Reducing Emissions from Deforestation and forest Degradation (REDD) and Improved Forest Management (IFM) project types can be hard to find. In addition to providing such guidance, this chapter aims to describe and relate the gaps and overlaps of these technical guidelines to the emerging methodologies from third-party offset standards. The major technical subjects for forest carbon inventories are briefly overviewed, focusing in particular on strategic choices for implementing a cost-effective inventory.

Successfully bringing forest carbon projects through the validation and verification stages will require attention to and documentation of technical details beyond the level of explanation that can be offered here. As such, this chapter highlights strong and timely treatment of technical subject areas among the multitude of existing guidebooks and directs readers to these sources for more detailed treatment of specific technical considerations.

## Box 1. Methodologies Covered in this Review

The relevant inventory guidance across forest carbon standards is usually spelled out in individual methodologies rather than standard-level documentation. In general, methodologies often allow for different forest survey methods so long as the procedures and data analysis are well-documented and scientifically justified. This review considers the methodologies approved under the Clean Development Mechanism as well as those approved and in the Verified Carbon Standard (formerly the Voluntary Carbon Standard) pipeline as of May 2011. In general, the concepts and strategies introduced here will be applicable to other methodologies beyond those reviewed. Nevertheless, we attempt to highlight key differences in inventory methodology considerations for other standards and methodologies where appropriate. Project developers should revisit any methodology they intend to use to make sure their inventory design and procedures are consistent with the most current version and its requirements. The methodologies considered in this review include:

- **Clean Development Mechanism (CDM)** large-scale AR methodologies (12) and small-scale AR methodologies (7) approved as of May 2011. See the latest methodologies approved and under development at <http://cdm.unfccc.int/methodologies/index.html>.
- **Verified Carbon Standard (VCS)** methodologies approved (9) or undergoing assessment/validation (4) as of May 2011. See all VCS methodologies at <http://v-c-s.org/>.

## 1.1 The Logic of Inventories

Inventories are employed to meet several needs in forest carbon project development:

- Calculating carbon storage at project initiation (i.e., time 0);
- Measuring incremental changes in carbon stocks;
- Informing models to predict forest growth in baseline and actual project scenarios; and
- Monitoring changes in carbon stocks due to human and natural disturbances.

The relative importance of each of these functions varies across the different forest carbon project types.

For Afforestation and Reforestation (**AR**) projects, forest carbon inventories serve primarily to document the incremental growth of trees over time. A time 0 inventory will establish the starting point for incremental growth, but in most AR projects the calculation of time 0 carbon storage will generally focus on measuring non-tree woody biomass (in addition to emissions associated with site preparation and clearing prior to planting) that may be required by relevant methodologies to quantify baseline carbon stocks. This initial inventory will generally not utilize the same measurement techniques or sampling intensity as later forest inventories when the primary carbon pool of interest will be aboveground tree biomass.

**IFM** projects utilize inventories in a similar manner to AR projects. Inventories in both AR and IFM projects primarily focus on documenting the incremental growth of tree biomass, and periodic inventories are used to inform the use of models that predict forest growth and—particularly in IFM projects—any silvicultural treatments planned over the lifetime of the project. For IFM projects, however, the reliable measurement of the forest at project initiation (time 0) is critical, as it will inform the modeling exercises for predicting baseline (or “without-project”) and actual (or “with-project”) scenarios into the future. For both AR and IFM projects, periodic inventories should inform the use of models that predict forest growth and any silvicultural treatments planned over the lifetime of the project.

For **REDD** projects, the primary emphasis of an inventory is establishing the estimate of carbon storage at project initiation (time 0), in both forest strata and post-conversion vegetation (i.e., the biomass in agricultural or other systems after deforestation). This estimate will form the basis for determining the emissions corresponding to the deforestation or degradation baseline. In some REDD projects, inventories may be applied to track incremental growth—such as where degraded forest is recovering—but this type of accounting is not accepted in all REDD methodologies.

In all project types, the field inventory will be used for monitoring disturbance events over the life of the project. Depending on the project’s circumstances, it may also be used to inform estimates of project leakage.

## 1.2 Inventories in the Project Cycle

In general, the timing of inventories is predictable. The first full inventory will typically occur during the first year of project implementation, and subsequent monitoring events will generally occur at defined intervals over the life of the project. Ideally, the inventory design will be informed by the choice of a carbon accounting methodology (see Step-by-Step Overview), and the preparation of a Project Design Document will require information obtained from the first inventory. Depending on the amount of background information and forestry statistics available for the forest types in the project area, a pre-inventory may be pursued during the feasibility assessment step.

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*The first full inventory typically occurs during the first year of project implementation.*

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The measurements collected in the inventory are critical to achieving successful validation and should reinforce confidence in any preliminary estimates of time 0 carbon storage. Biomass estimates from the first inventory (particularly for aboveground tree biomass) will be used in the quantification of potential emissions reductions from a REDD or IFM project, including determining potential timber revenue reductions associated with implementing carbon project activities. For AR projects that clear and/or burn project lands to prepare tree planting, a biomass inventory will need to be conducted prior to the implementation of site preparation and planting to account for any carbon losses.

## 2. Good Practice and Accounting Framework

Forest carbon inventory design and implementation should always follow good practice guidance that has been endorsed by the specific carbon programs, such as the Clean Development Mechanism (CDM) or the Verified Carbon Standard (VCS). The Intergovernmental Panel on Climate Change (IPCC) provides guidance on best practices<sup>1</sup> including for Land Use, Land-Use Change, and Forestry (LULUCF).<sup>2</sup> The IPCC's Good Practice Guidance informs many aspects of standardized project assessment and certification and should be a familiar reference for forest carbon inventory managers.

The 2003 LULUCF Good Practice Guidance (hereafter IPCC GPG-LULUCF) set a benchmark for projects:

Inventories consistent with *good practice*... should ensure that estimates of carbon stock changes, emissions by sources and removals by sinks, even if uncertain, are *bona fide* estimates, in the sense of not containing any biases that could have been identified and eliminated, and that uncertainties have been reduced as far as practicable given national circumstances.

The principles of scientific rigor and conservativeness are consistent across all standards and methodologies surveyed here. External auditors will expect every project to demonstrate an attempt to identify and eliminate biases, particularly those leading to over-estimation of project carbon benefits.

### 2.1 Conservativeness and Verifiability

As a general principle, most carbon standards and good practice guidance require conservative estimates of emission reductions over time. This means that those *carbon pools* that are expected to significantly decrease with project activities (compared to the baseline) or to significantly increase under the baseline scenario (compared to the project scenario) need to be accounted for. The same is true for those *emissions sources* that increase with project activities (compared to the baseline scenario) and those that would decrease under the baseline (compared to the project scenario). In addition, uncertainties related to sampling and other errors have to be taken into account to produce conservative estimates of a project's emission reductions.

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*The IPCC's Good Practice Guidance should be a familiar reference for forest carbon inventory managers.*

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Beyond observing the principle of conservativeness, the project developer<sup>3</sup> should also consider the perspective of the auditor who will be certifying that the inventory meets the specifications outlined in the chosen methodology and more general standards guidance. Auditors performing validation and verification will generally require rigorous

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<sup>1</sup> The IPCC published guidelines for national greenhouse gas inventories, including forestry and other land uses, in 1997, 2000, and 2006. These guidelines can provide helpful background information, but the 2003 guidance on Land Use, Land-Use Change, and Forestry holds more relevant information for forest carbon project developers.

<sup>2</sup> These IPCC good practice guidelines inform most carbon standards and methodologies. However, they are not generally explicitly invoked by these standards as compulsory approaches compared to any techniques not endorsed by the IPCC. Nevertheless, project proponents should endeavor to comply with IPCC guidance because auditors will be more likely to reject methods and techniques that are inconsistent with IPCC guidance.

<sup>3</sup> In this series, the term "project developers" is used to refer specifically to entities tasked with the technical design aspects of the project as required by the carbon and/or co-benefit standard(s). "Project proponents," on the other hand, is used to refer to those individuals or organizations generally responsible for the overall organization, management, and legal representation of the forest carbon project.

documentation of measurement procedures and inventory design as well as for data collection, handling, and analysis procedures.

Project developers should exercise caution when considering the use of relatively novel or uncommon inventory practices.<sup>4</sup> Although auditors will not arbitrarily exclude particular inventory techniques that fulfill the general requirements of a particular methodology, the project developer will likely have to go to additional lengths to demonstrate to the auditor's satisfaction how the new technique complies with the relevant requirements. In particular, when implementing innovative inventory procedures, clearly demonstrating statistical soundness and conservativeness can be complex and time-consuming. Before choosing to implement an innovative technique, the project developer should weigh the benefits of implementing it during the inventory against the potential costs that may be incurred by efforts to convince an auditor of the validity of the approach.

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*Inventories must account for carbon pools that are expected to significantly decrease with project activities (compared to the baseline) or to significantly increase under the baseline scenario (compared to the project scenario).*

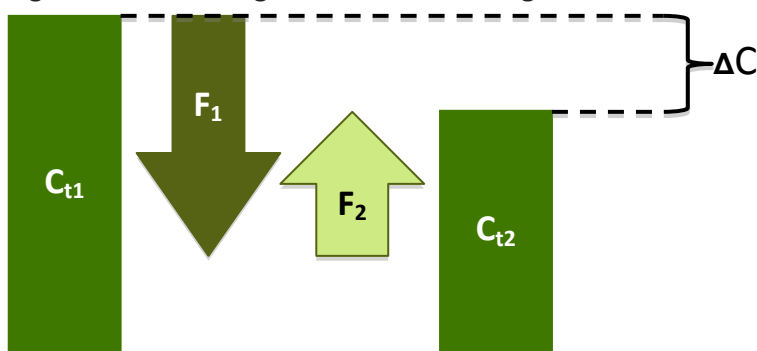
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## 2.2 Accounting Paradigms

IPCC GPG-LULUCF identifies two general approaches (see Figure 1) that may be applied to quantify the change in a particular carbon pool ( $\Delta C$ ):

- In the **flux or gain/loss approach**, the rate of carbon loss is subtracted from the rate of carbon gain in a forest over an accounting period to estimate a net change in carbon storage. Thus,  $\Delta C = F_2 - F_1$
- In the **stock change approach**, the stock of carbon stored in a particular pool is measured over an accounting period. The difference in pools provides the net change in carbon storage. Thus,  $\Delta C = C_{t1} - C_{t2}$

**Figure 1. Stock Change and Flux Accounting**



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<sup>4</sup> For example, the use of remote sensing technologies such as Light Detection and Ranging (LiDAR) or aerial digital imagery for the purposes of tree biomass estimation are very promising tools. While some methodologies may allow these types of approaches (e.g., Infinite Earth's VCS Methodology VM0004), the customization required to make these data accurate may result in increased auditor scrutiny. Remote sensing of this nature is currently likely to be cost-effective only for very large project areas.

### 2.2.1 Flux and Stock Change in Practice

In a forest carbon project, accounting methods assume familiarity with these principles. In practice, projects will often combine or use these approaches in tandem to estimate changes in carbon storage for different purposes. The specific accounting framework is determined by the methodology chosen and is not usually a matter of choice for the project developer.

In REDD projects, the calculation of total net emissions (equivalent to change in carbon storage) associated with conversion of forest land in a particular year will be based upon the application of an **emission factor** that specifies the amount of greenhouse gas (GHG) emissions associated with that conversion per unit area, multiplied by the area converted. These emission factors will usually be based upon before/after measurement of sample plots (i.e., stock change approach) that were converted in or around the project area, or by sampling plots in areas that have been converted and comparing them to plots from another location area representative of pre-disturbance carbon stocking. For further explanation of the methodologies applied to estimate a project's emissions reductions, see the AR and REDD guidance documents of this series.

When forest degradation is an important emissions source, such as in some IFM and REDD projects, a similar approach will be used. In this case, an emission factor associated with a particular practice (e.g., selective removal of large commercial timber species) will be calculated from field measurements from logged and unlogged stands within the project boundaries or from reference areas outside the project boundaries.

In circumstances where a source of emissions is difficult to measure directly, the flux approach may be applied to indirectly calculate the net effect of a particular activity. For example, unsustainable extraction of biomass for fuelwood can lead to progressive degradation of a forest area but is difficult to measure directly. By surveying the community gathering fuelwood, the project developer may estimate the net biomass extracted from the forest over time and calculate the emissions associated with removal and combustion of that biomass.

#### Box 2. Key References for Good Practice Guidance and Accounting

Generally considered the authority for Good Practice Guidance and the foundation for many current forest carbon standards:

IPCC. *Good Practice Guidance for Land Use, Land-Use Change and Forestry*. Hayama, Japan: Intergovernmental Panel on Climate Change, 2003. Available at: : [http://www.ipcc-nggip.iges.or.jp/public/gpplulucf/gpplulucf\\_contents.html](http://www.ipcc-nggip.iges.or.jp/public/gpplulucf/gpplulucf_contents.html)

In addition to IPCC GPG-LULUCF, further elaboration of good practice for offset projects in general can be found in:

Daviet, Florence, Suzie Greenhalgh, and Emily Weninger. *The Land Use, Land-Use Change, and Forestry (LULUCF) Guidance for GHG Project Accounting*. Washington, DC: World Resources Institute, 2006. Available at: <http://www.wri.org/publication/land-use-land-use-change-and-forestry-guidance-greenhouse-gas-project-accounting>.

For a more direct and sustained focus on good practice for forest carbon projects, consult

Watson, Charlene. *Forest Carbon Accounting: Overview & Principles*. Addis Ababa, Ethiopia: UNDP and UNEP, 2009. Available at: <http://www.beta.undp.org/undp/en/home/librarypage/environment-energy/climate-change/forest-carbon-accounting-overview---principles.html>.

## 3. Inventory Design and Planning

Planning a forest carbon field inventory is fundamentally about answering three key questions:

1. Which forest carbon pools and land areas should be measured?
2. How will these pools be measured?
3. How will the inventory approach cost-effectively meet desired precision levels?

The answers to questions 1 and 2 are usually relatively straightforward and receive explicit treatment by the standards and methodologies themselves. Many of the major methodological specifications are given in Table A1 (see Appendix). The scientific literature on how to measure and estimate forest carbon stocks and changes is also generally robust and provides a critical source for specific measurement procedures.

The answer to the third question, however, is much more nuanced. Standards and methodologies will always provide general requirements regarding precision and sampling; many also include helpful recommendations. Nevertheless, the project developer will typically be faced with ambiguities and seemingly implied preferences when navigating the finer details of inventory planning under a chosen methodology's framework. The following sections will briefly discuss the first two questions before moving into a more detailed consideration of the major choices in designing a cost-effective sampling strategy. This is preceded by some notes about human resource needs and standard operating procedures.

### 3.1 Setting the Stage for the Inventory

#### 3.1.1 Expertise and Staffing Considerations

The overall strategy and design for the project's carbon inventory should be led by an experienced forester or natural resource manager with a clear understanding of the unique needs of and expectations for carbon inventories, including how they are distinct from more common commercial timber inventories. In countries where the forestry industry is well-developed, sufficient expertise may exist at a national level. However, the insight of a global-level forest carbon expert will be a safe investment to verify the inventory is planned in a way that will avoid unnecessary delays in validation or verification.

Field teams should be led by a forest surveyor with experience conducting inventories in the forest types covered by the project, and all personnel participating in the forest inventory should be provided Standard Operating Procedures (SOPs) and instruction as necessary to ensure consistent application of procedures by all surveyors.

For projects in which local communities are closely tied to the success of the project activities, it may be desirable to involve community members in the inventory or monitoring activities to encourage local awareness of the measurement framework and ongoing project performance.<sup>5</sup>

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<sup>5</sup> See additional guidance on the potential for using community-based forest measurement and monitoring, including case studies, from Skutsch (2010).

### Box 3. Participatory Geographic Information System

Several forestry projects to date have pursued a participatory Geographic Information System (P-GIS) approach to engage local residents and stakeholders in the process of surveying and mapping the project area, in addition to providing valuable information on the history and current land-use patterns associated with project areas. The two most comprehensive guides to date on planning and deploying a P-GIS are:

- Verplanke, J.J., and E. (Eds.) Zahabu. *A Field Guide for Assessing and Monitoring Reduced Forest Degradation and Carbon Sequestration by Local Communities*. Enschede, The Netherlands: Project team Kyoto, 2009. Available at: <http://www.mountainforum.org/en/node/13410>
- Amazon Conservation Team. *Methodology of Collaborative Cultural Mapping*. Brasilia, Brazil: Amazon Conservation Team Brazil, 2008. Available at: [http://www.equipe.org.br/publicacoes\\_dentro.php?tipoid=1](http://www.equipe.org.br/publicacoes_dentro.php?tipoid=1).

#### 3.1.2 Standard Operating Procedures

Before beginning the full inventory effort, the inventory planner should write down clear procedures for collecting field (and any laboratory) measurements. These include rules for how plots are located and marked; what systems and codes to use for numbering; what variables will be measured and which tools to use in measuring them; and how to handle predictable anomalies such as unusual tree shapes, plots containing roads or streams, and strongly sloped or undulating terrain. The SOPs should also cover how any electronic data should be entered and stored. Quality Assurance and Quality Control

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*The inventory planner should prepare a suite of quality assurance and quality control steps to maintain the quality of data collected through any further analysis.*

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Quality assurance and quality control (QA/QC) are closely related terms that emphasize the prevention and correction of errors. Although some forest carbon methodologies contain specific QA/QC criteria for forest inventories and monitoring activities, many do not. To prepare for validation and to ensure accurate quantification of forest carbon stocks and changes, the inventory planner should prepare a suite of QA/QC steps to maintain the quality of data collected through any further analysis.

Common QA/QC procedures include repeated measurement of 10-20% of plots by separate individuals, including (Pearson, Brown and Birdsey 2007):

- Hot checks: a supervisor oversees plot measurement of field team on the spot to immediately identify and correct any systematic measurement errors.
- Cold checks: a supervisor re-measures a plot after the departure of the field crew, comparing new measurements to previously collected measurements and reconciling substantial (e.g., >5%) discrepancies.
- Blind checks: A supervisor or other crew member re-measures a plot without knowledge of the earlier measurements. Measurements are not reconciled but are maintained as an indication of uncertainty in inventory measurements.

QA/QC procedures should also be developed for data entry and storage as well as any laboratory analyses and equipment used.



#### Box 4. Further Guidance for QA/QC Procedures

Among the methodologies surveyed here, CDM methodology AR-AM0004 v4 contains the most detailed set of QA/QC criteria and may serve as a good practice guide for projects using methodologies without such guidance. That methodology is available at:

<http://cdm.unfccc.int/methodologies/DB/S2OMSUTOWYOMLW75MPROCG6SAKNG4Y>.

Terra Global Capital's VCS REDD Methodology (VM0006) provides detailed QA/QC guidance and may also serve as a good starting point. Available at: <http://www.v-c-s.org/VM0006.html>.

For further guidance on QA/QC, also consult:

- IPCC. *Good Practice Guidance for Land Use, Land-Use Change and Forestry*. Hayama, Japan: Intergovernmental Panel on Climate Change, 2003. Available at: [http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf\\_contents.html](http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_contents.html)
- Pearson, Timothy, Sarah Walker, and Sandra Brown. *Sourcebook for Land Use, Land-Use Change and Forestry Projects*. Winrock International and World Bank BioCarbon Fund., 2005. Available at: [http://www.winrock.org/ecosystems/files/winrock-biocarbon\\_fund\\_sourcebook-compressed.pdf](http://www.winrock.org/ecosystems/files/winrock-biocarbon_fund_sourcebook-compressed.pdf).
- GOFC-GOLD. A sourcebook of methods and procedures for monitoring and reporting anthropogenic greenhouse gas emissions and removals caused by deforestation, gains and losses of carbon stocks in forests remaining forests, and forestation. Report version COP16-1, Alberta, Canada: Natural Resources Canada, 2010. Available at: [http://unfccc.int/files/methods\\_science/redd/methodologies/other/application/pdf/sourcebook\\_version\\_nov\\_2009\\_cop15-1.pdf](http://unfccc.int/files/methods_science/redd/methodologies/other/application/pdf/sourcebook_version_nov_2009_cop15-1.pdf).

## 3.2 Mapping and Stratifying the Project Area

### 3.2.1 Mapping the Project Area

Properly defining the geographic scope of the project is a critical first step for developing a forest carbon inventory. A base map of the project area should be completed with clear delineation of relevant boundaries and geographic features including forest groupings, soils, topography, and hydrology. In addition, the extent of any land areas controlled by specific regulations should also be documented, including any restrictions on timber harvesting, land clearance, or other conservation requirements (including for baseline development). Determination and mapping of land eligibility according to the standard and methodological rules will also be a critical part of the project area map. Mapping the forest areas according to relevant tenure and land title groupings may also be advisable for future project management decisions, although it is not strictly necessary for inventory analysis itself.

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*The scope and nature of planned project activities will also inform the choice of project boundaries.*

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The scope and nature of planned project activities will also inform the choice of project boundaries. For REDD projects, this will include identification of activities for addressing deforestation and degradation pressures and where these will be implemented. Projects typically have some flexibility to design project boundaries strategically. For example, in REDD projects, including areas unlikely to be under pressure of deforestation for many years will often lead to additional costs and complexities. Including such areas will increase the area that must be assessed for baseline determination and leakage monitoring but will not produce additional emission reductions or revenues. For AR projects, the relevant scope may focus on planted areas while also extending to managed areas that will regenerate due to project interventions (e.g., through fire suppression and /or the seed source provided by project plantings).



Project developers who have significant flexibility in the delineation of project boundaries should weigh the costs and benefits of several boundary options, taking into consideration potential carbon and other revenues as well as additional monitoring and other project implementation costs.

The AR and REDD guidance documents detail further criteria that need to be considered in determining project boundaries, including establishing “control over project area” and a management plan to actually implement activities throughout the project area. The standard and methodology chosen for forest carbon accounting will also include additional requirements defining land eligibility such as forest definitions,<sup>6</sup> and more recently, the use of reference areas for deforestation and degradation calculations, as well as leakage belts or buffer areas that extend beyond the project boundaries for monitoring purposes. The inventory and monitoring requirements for these different areas will be discussed further below.

### 3.2.2 Stratification and Pre-Inventory

The process of dividing a diverse forest landscape into areas with shared characteristics is known as stratification. It is a valuable step for generating accurate inventory and monitoring data while limiting the costs for doing so. The principle behind stratification is to compartmentalize the variability across the forest by grouping stands into units that are relatively homogenous regarding the variable being measured.

Common data layers used to inform stratification include data derived from maps, aerial or satellite imagery (allowing for visual differentiation), soil classifications, and terrain layers with slope and or hydrologic features (indicating different growth conditions). Any forest management information—including age classes, logging history, and forest type—will also be helpful to delineate strata.<sup>7</sup> The most important attributes commonly used to stratify the project area are forest type (determined including elevation and annual average precipitation and temperature), followed by stand age, topographic position, and disturbance history.

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*Stratification does not need to address potential developments that have not yet produced changes in current stocks or growth conditions.*

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When choosing criteria to delineate strata, it is important to keep in mind that stratification is primarily concerned with grouping areas based on current shared characteristics, not potential changes in the future such as likelihood of disturbance. Regarding human disturbance criteria, stratification may take into account those factors (e.g., distance to settlements, roads, etc.) that have already had an impact on carbon stocking or growth conditions, but it does not need to address potential developments that have not yet produced changes in current stocking or growth conditions. For example, for an AR project, it may be best to stratify the project area based on the age class of trees based on years of planting. In contrast, in any project type, distance to roads or other human features does not justify additional stratification unless a relationship already exists between distance to roads and current carbon stocks. For

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<sup>6</sup> Under the CDM, each country must provide its own quantitative criteria for defining forest land based on the areal percent of crown cover, the average height of trees, and minimum contiguous land area. Countries may also restrict the definition of based on tree types, for example limiting eligibility for palm trees and bamboo. If a country has submitted a forest definition to the CDM, it can found by searching for the country's name at <http://cdm.unfccc.int/DNA/index.html>.

<sup>7</sup> Although most methodologies don't elaborate many details on the integration of pre-existing forest inventory data, Carbon Planet's VCS methodology (VM0011) “Methodology for Improved Forest Management – Logged to Protected Forest: Calculating GHG Benefits from Preventing Planned Degradation” provides guidance and criteria for utilizing previous inventory data, which includes comparing of the similarity of strata identified in the current and previous inventories. For more information see <http://v-c-s.org/methodologies/VM0011>.

example, in a REDD project where degradation has been observed near roads, distance to roads may be a worthwhile stratification component.

Drawing the boundaries of every stratum will be most effective using a GIS program. Choosing where to draw boundaries in IFM and REDD projects can often be challenging if remotely-sensed data is not easily interpreted and no previous forest inventory data exists. To overcome this initial hurdle, it is commonly recommended to conduct a “preliminary inventory,” with at least 10 sample plots established in each supposed stratum. A pre-inventory will provide basic estimates of the carbon stock and variability of relevant carbon pools in order to decide, among other things, on the necessary minimum number of field plots for the full inventory. The pre-inventory is also an opportunity for the inventory supervisor to perform training “hot checks” with field crews and familiarize them with data collection and handling procedures.

### Box 5. The Power of Stratification

The utility of stratification to project developers is evident in the comparison of two case studies: the Guaraqueçaba Climate Action Project in Brazil, which covers about 4,400 ha, and the Noel Kempff Mercado Climate Action Project in Bolivia, which covers an area of more than 630,000 ha. Inventories for both projects, planned by Winrock International, distinguished six forest cover types (or strata) for sampling. The Guaraqueçaba project placed an average of 1 plot per 23 hectares, with 188 plots total (Tiepolo, Calmon and Feretti 2002). Noel Kempff used 1 plot per 1,015 hectares, with 625 plots total (Powell 1999). Guaraqueçaba achieved a level of precision with sampling errors of 0.4% to 5.7% of the mean for different carbon pools across all sampled strata using a 95% confidence interval. Noel Kempff achieved precision levels with sampling errors of 4.0% of the mean across all strata and carbon pools, also using a 95% confidence interval (see Section 3.4.1 for a discussion of confidence intervals and sampling errors).

Although the forest area being surveyed was nearly 150 times greater at Noel Kempff, the survey only required just over 3 times the number of plots. Because plot numbers in stratified sampling are determined by the expected variability of carbon stores in each stratum and the chosen levels of precision, the total number of plots is not dependent on the spatial extent or distribution of project sites in the area being surveyed.

Several CDM and VCS methodologies address considerations for updating strata boundaries. For example, the Avoided Deforestation Partners VCS REDD Modules require clusters of plots that show average carbon storage beyond 20% of the mean for their stratum to be classified into a new stratum. In a similar vein, disturbances or other developments over time may result in a plot more closely fitting with the carbon stocking of another stratum. Updating strata over time to continue grouping homogenous stands and removing boundaries that are no longer meaningful may also help to reduce monitoring sampling needs, particularly in the case of IFM projects where harvest activities may change carbon stocks significantly.

Since the value of stratification is primarily to cut the sample size required to meet particular precision levels, if stratification ends up indicating a larger number of plots would be required than if no (or fewer) strata were devised, then project developers should reconsider—or even abandon—the stratification approach, as long as their methodology allows them to do so. In general, however, stratification will lead to reduced overall sampling intensity in inventories in both natural and planted forest ecosystems.

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*If stratification leads to a larger number of plots than if no (or fewer) strata were devised, then project developers should reconsider, or even abandon, stratification.*

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## Box 6. Additional Guidance on Stratification

IPCC. *Good Practice Guidance for Land Use, Land-Use Change and Forestry*. Hayama, Japan: Intergovernmental Panel on Climate Change, 2003. Available at:  
[http://www.ipcc-nggip.iges.or.jp/public/gpplulucf/gpplulucf\\_contents.html](http://www.ipcc-nggip.iges.or.jp/public/gpplulucf/gpplulucf_contents.html)

*Outlines the common resources that can be used to inform stratification.*

Tito, Marcos Rugnitz, Mario Chacón León, and Roberto Porro. *Guía para la determinación de carbono en pequeñas propiedades rurales*. ICRAF Technical Manual No. 11, Lima, Peru: World Agroforestry Centre – Amazon Regional Programme, 2009. Available at:  
<http://www.iamazonica.org.br/ianet/documento/baixadoc.php?file=071209060340.pdf>.

*The most thorough discussion of stratification strategies for forest carbon projects in Spanish.*

GOFC-GOLD. A sourcebook of methods and procedures for monitoring and reporting anthropogenic greenhouse gas emissions and removals caused by deforestation, gains and losses of carbon stocks in forests remaining forests, and forestation. Report version COP16-1, Alberta, Canada: Natural Resources Canada, 2010. Available at:  
[http://unfccc.int/files/methods\\_science/redd/methodologies/other/application/pdf/sourcebook\\_version\\_nov\\_2009\\_cop15-1.pdf](http://unfccc.int/files/methods_science/redd/methodologies/other/application/pdf/sourcebook_version_nov_2009_cop15-1.pdf).

*Good guidance on approaches to stratification in English.*

## 3.3 What to Measure in the Full Inventory

The prescriptions for physically measuring aboveground biomass and other forest carbon pools are covered in great detail in references provided by methodologies themselves, forest carbon guidebooks such as the *Sourcebook for Land-use, Land-use Change and Forestry Projects* (Pearson, Walker and Brown 2005), and a wealth of other literature. The discussion in the following sections assumes basic knowledge of these procedures; many technical details of forest mensuration are not revisited here.

### 3.3.1 Required and Optional Pools

The emissions scope of the project will be set by identifying which forest carbon pools and emissions sources shall be measured. The conservativeness principle (see above, Section 2.1) applies when choosing to account for or neglect certain optional carbon pools or sources of emissions. In addition, certain carbon pools and emission sources may be neglected in carbon accounting and reporting if they are not considered “significant.” The CDM “Tool for testing significance of GHG emissions in A/R CDM project activities” specifies:<sup>8</sup>

The sum of decreases in carbon pools and increases in Greenhouse Gas emissions that may be neglected (i.e., considered ‘insignificant’) shall be less than 5% of the total CO<sub>2</sub>-eq benefits generated by the project.

The VCS has adopted a corresponding “de minimis” regulation in that “GHG sources that account for less than 5% of the total emissions reductions generated by the project are considered ‘insignificant,’” determined by using the same CDM Tool. For most methodologies, “optional” pools will actually require significance testing before they may be conservatively excluded from project accounting. Pools that cannot be conservatively ignored must be accounted for through field and laboratory measurements, as appropriate. This means that the project does not have discretion to forego accounting for any required or optional pools that do not justify exclusion on grounds of conservativeness or insignificance.

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<sup>8</sup> Available at: <http://cdm.unfccc.int/methodologies/ARmethodologies/tools/ar-am-tool-04-v1.pdf>.

### 3.3.2 Emissions from Site Preparation

For many AR projects, and some IFM projects, the clearing and/or burning of pre-project vegetation on plots in preparation for tree planting will need to be accounted for. These emissions from site preparation are accounted for by applying combustion factors to biomass values collected during an inventory of vegetation prior to site preparation. The CDM A/R Methodological Tool “Estimation of GHG emissions due to clearing, burning and decay of existing vegetation attributable to a CDM A/R project activity” (Version 03) gives combustion factors for both CO<sub>2</sub> and CH<sub>4</sub> for above- and below-ground biomass of trees and shrubs to calculate emissions from site preparation.<sup>9</sup>

#### Box 7. Relevant CDM Tools and Guidance for Optional Pools

All of the following tools may help inform the decision process on which pools to measure and also provide direction to preferred methods of measurement. The most recent versions of these and other CDM tools may be found at <http://cdm.unfccc.int/methodologies/ARmethodologies/approved>.

- The 5% materiality threshold from the *Tool for testing significance of GHG emissions in A/R CDM project activities* is the most widely-used benchmark for determining the materiality of emissions sources and carbon pools required for project accounting.
- Projects that do not elevate erosion or occur on organic soils may ignore soil organic carbon, as described in *Procedure to determine when accounting of the soil organic carbon pool may be conservatively neglected in CDM A/R project activities*.
- The decision-making process for conservatively excluding site preparation emissions under the CDM can be found in *Guidance on conditions under which GHG emissions from removal of existing vegetation due to site preparation are insignificant*. The most recent version of this and more CDM guidance is available at [http://cdm.unfccc.int/Reference/Guidclarif/ar/index\\_guid.html](http://cdm.unfccc.int/Reference/Guidclarif/ar/index_guid.html).

### 3.3.3 Electing to Account for Optional Carbon Pools

Every methodology requires accounting for aboveground biomass, but most other pools are either optional or excluded, depending on which methodology is chosen. Which of the optional pools may be most relevant will vary by project type and site dynamics. For example, measuring litter and downed dead wood for AR projects is not likely to produce any substantial carbon volumes until much later in stand development. These pools are also highly variable, and detecting changes in the size of the pools over time may be more time consuming or costly than justified by potential carbon credit revenues.

Soil carbon stocks accumulate slowly and are highly variable even in nearby locations. Detecting increases in soil carbon storage will often not be cost-effective, although these costs have steadily decreased in recent years. In circumstances where the loss of soil carbon (and carbon in downed dead wood) through deforestation is thought to be substantial, it may be worthwhile to measure these pools in forest and nearby agricultural fields or pastures to estimate the magnitude of change that may be expected.

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<sup>9</sup> At the 42<sup>nd</sup> meeting of the CDM Executive Board, the Board issued a ruling that the emissions from removal of herbaceous (i.e., non-woody) biomass do not need to be taken into account for AR projects under the CDM. That text is available at: [http://cdm.unfccc.int/Reference/Guidclarif/ar/methAR\\_guid21.pdf](http://cdm.unfccc.int/Reference/Guidclarif/ar/methAR_guid21.pdf).

Recognizing the cost and difficulty in detecting changes in variable and slowly-changing pools, some methodologies may allow for the use of default factors or lookup tables to estimate the changes in pools such as downed dead wood, litter, and soil carbon. For example, the CDM offers two tools to calculate conservative estimates of changes in the dead wood and litter pools, as well as soil carbon.<sup>10</sup> These tools give conservative default values, and projects have the option to produce less conservative measurements by conducting actual field measurements, with

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*There are significant opportunities for synergy between carbon and timber inventories.*

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associated costs. Note that not all methodologies allow for the inclusion of certain carbon pools, regardless of what approach might be chosen.

We encourage project developers to at least use a pre-inventory to help provide additional insights into the costs and benefits of potentially including other carbon pools if they are considering accounting for optional pools. Thoughtful consideration of the likely effects of planned project activities on the magnitude of carbon stocks compared to baseline trajectories for these optional carbon pools should be combined with evaluation of the cost and sampling effort necessary to detect changes in these pools over time. For example, simply being confident that stocks of downed dead wood will increase due to a shift in management practices is not sufficient evaluation; the high variability of this pool<sup>11</sup> makes detecting change very difficult, and either the sampling effort or the magnitude of the change will likely need to be very large in order to detect incremental changes. Measurement costs will then need to be compared to realistic additional revenues from accounting for the downed dead wood pool.

### 3.3.4 Measuring Timber Variables

If the project activities will include timber harvesting or other silvicultural activities, it will be important to make sure that any relevant data to support forest management decision-making is also collected during the carbon inventory. Timber management may often consider variables beyond those collected through a forest carbon inventory. Documenting form class, length of merchantable bole (logs), taper, defect, etc. may not necessarily be part of a carbon inventory if the project case will not involve timber harvest, but will often be valuable for planning timber harvesting. There are, thus, significant opportunities to create synergies between carbon and timber inventories, and the relevant expertise for both fields should be brought together if project activities include timber harvests.

### 3.3.5 Calculating Forest Carbon Stocks from Field Measurements

Carbon stocks will be calculated at the plot level for each pool measured; the mean and variation across all plots in a stratum will then allow for developing a per-area estimate of average carbon stocks in each pool. This will also indicate whether the precision target has been met or if the sample size needs to be increased. The mean carbon storage calculated for the strata is then extrapolated across the project area based on the respective area of each stratum.

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<sup>10</sup> For the tool “Estimation of carbon stocks and change in carbon stocks in dead wood and litter in A/R CDM project activities” see <http://cdm.unfccc.int/methodologies/ARmethodologies/tools/ar-am-tool-12-v1.1.0.pdf>. For the Tool for estimation of change in soil organic carbon stocks due to the implementation of A/R CDM project activities, see <http://cdm.unfccc.int/methodologies/ARmethodologies/tools/ar-am-tool-16-v1.1.0.pdf>.

<sup>11</sup> The size, variance, and persistence of downed woody debris can vary dramatically in and between forests. Choosing to monitor optional carbon pools should be informed by a scientific understanding of whether changes in these pools compared to the baseline are likely to be large enough to be statistically detectable and large enough to contribute substantially to the volume of emissions reductions generated by the project.

Calculating carbon stocks involves applying conversion factors to determine the biomass and carbon content from the measurements collected in the field. These calculations are detailed in several other guidebooks and in the scientific literature (see Box 8). For the most part, there is not much room for strategic choices in the use of these equations, as their use will be set out by the relevant guidance or methodologies. For aboveground biomass, however, carbon calculations usually take one of two forms: allometric equations or biomass expansion factors. Many times, the choice between these two approaches is a strategic one.

**Allometric equations** are regressions that are derived from harvested trees and to relate variable(s) measured (e.g., diameter at breast height (DBH) and tree height) to variable(s) of interest (e.g., aboveground tree biomass). Allometric equations translate measured variables directly into the unit of interest. Project developers may consult IPCC GPG-LULUCF (4.A.1-4.A.3) for a list of allometric equations contained in peer-reviewed publications for trees around the world.<sup>12</sup> There may also be more area-specific scientific studies for particular species or genera of interest (e.g., on the national or even local level, and these should generally be preferred) and may in fact be required where they exist—over more general default values. Project developers required to develop new allometric equations will find that the process is not particularly complicated as it can be completed with a relatively brief sampling effort of ~30 trees for a particular species or grouping of similar species.<sup>13</sup>

**Biomass expansion factors** (BEFs) are dimensionless factors that can translate plot-level measurements commonly collected from timber inventories, such as merchantable volume, into aboveground biomass volume estimates. These volume estimates are then converted into biomass using specific wood density values. Conservative default values for different forest types and regions are provided by IPCC GPG-LULUCF (Table 3A.1.10).<sup>14</sup>

Choosing to use allometric equations or biomass expansion factors is most often not a choice between varying levels of scientific or statistical rigor, but rather a decision that tends to be based upon the availability of pre-existing data from a commercial timber inventory (which typically provides merchantable volume estimates). In circumstances where pre-existing inventory data exists, volumes may be converted to carbon values using BEFs. Where such data do not already exist, inventories for carbon projects will typically follow a direct tree measurement of diameter, height, etc. and the application of allometric equations. Therefore, the net practical benefit of choosing BEFs or allometric equations depends primarily on the availability of pre-existing data.

For projects in areas where local equations are not available, conservative BEFs from the IPCC GPG-LULUCF may be used in lieu of developing new allometric equations, potentially saving some cost associated with the research effort in developing project specific equations. BEFs are allowed by all CDM methodologies and most VCS methodologies. It is important to note however, that both the Avoided Deforestation Partners (VM0007) and Wildlife Works Carbon (VM0009) REDD Methodologies omit BEFs, dealing only with allometric equations.

### Inventory Compilers and Growth-and-Yield Models

Inventory compiling (also commonly known as “cruise compiling”) software may be available to transform the measurements collected in the field into volume, biomass, and potentially even carbon stock estimates. Although some timber-focused software programs do not create estimates for non-tree biomass (carbon) pools, but many major cruise compiling programs now offer these features.

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<sup>12</sup> IPCC allometric equation tables are available at [http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf\\_files/Chp4/Chp4\\_4\\_Annexes.pdf](http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/Chp4/Chp4_4_Annexes.pdf).

<sup>13</sup> A brief summary of how to develop biomass regression equations can be found in Appendix B of Pearson, Walker and Brown (2005).

<sup>14</sup> Available at [http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf\\_files/Chp3/Anx\\_3A\\_1\\_Data\\_Tables.pdf](http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/Chp3/Anx_3A_1_Data_Tables.pdf).

Growth-and-yield models may also be available to estimate the effects of forest growth and management interventions using field data. The availability and sophistication of these models for a specific forest or plantation type will vary from country to country. More sophisticated growth-and-yield models may also be able to incorporate repeated measurements over time to calibrate growth projections to local conditions. Project developers considering using a growth-and-yield model should verify that the model is valid for the project's specific region and forest types. For example, many growth-and-yield models have been built and calibrated to simulate single-species forest plantations and, thus, may be poorly-suited for modeling restoration of natural forests with multiple species or even commercially managed forests using uneven age management.

Experienced forest surveyors in the region, from timber industry, government forest inventory programs, or the ecological research community should be able to identify existing software programs that contain the relevant allometric equations or biomass expansion factors for use in a specific project.

### Box 8. Simple Growth Models

Two simple forest growth models with international scope, based on Excel spreadsheets, may help to provide rough estimates of the carbon impact of project activities. Although neither of these models allows calibrating growth to local field data, and may therefore not be adequate for detailed project planning, they can help in the feasibility assessment phase of project design.

CO2FIX is a model that was designed cooperatively by several research institutions. Though it is primarily used for tropical forest plantations, it also models growth of other forest types.

Available at: <http://www.efi.int/projects/casfor/>.

The USAID Carbon Calculator was developed by Winrock International and allows users to enter summary forest data to model AR, REDD, or IFM-type activities. Available at: <http://winrock.stage.datarg.net/gcc/>.

## 3.4 Precision Targets and Cost-Effective Sampling

### 3.4.1 Setting the Goalposts for Inventory Precision

A major overarching target for a forest carbon inventory is to achieve pre-determined levels of precision. The precision of a forest inventory is often assessed by comparing two statistics:

- A confidence interval that shows a range of plausible values for which—if the survey was repeated numerous times—there is a specific probability (usually 90% or 95%) that the true average is within the range of measurements. The more precise the measurement and less variable the samples within a surveyed area, the narrower the confidence interval.
- An allowable level of error presented as a percentage of the mean, with 10% being a common value. This means that the range of the confidence interval must be equal to or smaller than 10% of the average forest carbon storage. The larger the allowable error, the more difficult it will be to confidently show changes in forest carbon storage over time.
- The major factors affecting precision in a forest carbon inventory are the level of variability or heterogeneity in the forest being surveyed, the method for dealing with heterogeneity (e.g., stratification), the number and type of sampling plots, and the arrangement and location of those plots.



The major factors affecting precision in a forest carbon inventory are the level of variability or heterogeneity in the forest being surveyed, the method for dealing with heterogeneity (e.g., stratification), the number and type of sampling plots, and the arrangement and location of those plots.

### Box 9. Accuracy and Precision

**Accuracy** and **precision** are two independent, but commonly conflated, concepts. Husch, Beers and Kershaw (2003) define accuracy as “the closeness of a measurement to the true value.” The IPCC *Special Report on Land Use, Land-Use Change and Forestry* (2000) adds, “accurate estimates are unbiased in that they do not systematically under- or overstate the true number.”

Husch, Beers, and Kershaw (2003) also offer a clear definition for precision as “the degree of agreement in a series of measurements.” Thus, in contrast to accuracy—which denotes closeness to the true value—precision simply denotes closeness of measurements to each other (however inaccurate they may be).

In terms of internal inventory benchmarks, tests comparing the confidence interval and allowable level of error technically only assess the precision of an inventory. The clustering of measurements from different plots in each forest stratum indicates the precision of an estimate of carbon storage for that forest type.

The accuracy of an inventory effort can partially be assessed through the completion of independent spot-checks. By having different members within a team repeat the measurement of particular plots or pools within a plot, one can identify and hopefully resolve any systematic bias that may be inadvertently introduced by individual members of the inventory field team. This is a commonly recommended QA/QC procedure, which may also be repeated by an auditor during validation or verification site visits. Note, however, that although a systematic bias by an inventory team can be addressed through spot checks, bias that reduces accuracy can also be present in equations and measurement methods themselves.

Increasing the number of sample plots will generally decrease the size of the confidence interval. However, the relationship between the number of plots required to meet specific precision targets is not linear; rather, the number of plots required to meet desired precision benchmarks increases exponentially as higher levels of precision are targeted.

The experience of the Noel Kempff Mercado Climate Action Project in Bolivia offers an illustrative example of the potential sampling ramifications for increasing precision benchmarks. The project area (>600,000 ha) was stratified into six forest cover types. In the design of the ongoing monitoring plan, the inventory planners (Winrock International) evaluated a range of choices in terms of allowable error from 5% up to 30%, using a 95% confidence interval. Table 1 demonstrates the exponentially higher requirements for plots under a lower allowable error.

**Table 1. Plot Numbers with Varying Precision Benchmarks**

		Estimated Number of Plots by Allowable Error (% of Mean)			
Stratum	Area (ha)	+/- 5%	+/- 10%	+/- 20%	+/- 30%
Tall Forest	226,827	200	36	6	2
Liana Forest	95,564	33	6	1	0
Flooded Tall Forest	99,316	72	13	2	1
Flooded Short Forest	49,625	37	7	1	0
Mixed Liana Forest	159,471	108	19	3	1
Burned Forest	3,483	2	0	0	0
Total	634,286	452	81	14	4

*Adapted from Powell (1999).*



Every methodology surveyed for this chapter specifies a confidence level and allowable sampling error as a percentage of the mean carbon estimate. Some methodologies require this test to be applied separately for each carbon pool measured while others will only require it for the total estimate of forest carbon storage, summing all pools. Most of the methodologies set these precision benchmarks as hard limits, that is, inventories are not acceptable for offset quantification unless they meet these precision levels. Others use a discounting system where inventories with lower precision receive larger deductions from the mean carbon estimate (based on the level of sampling error beyond the benchmark). This approach is used, for example, by the Avoided Deforestation Partners REDD Methodology Uncertainty Analysis Module (VMD0017 X-UNC), the Wildlife Works VCS REDD Methodology (VM0009) and other carbon standards apart from VCS as well. This policy incentivizes projects to meet precision benchmarks to ensure full crediting up to the mean while also giving project proponents some flexibility to balance the increased effort and costs with associated additional revenues.

### 3.4.2 Choosing a Sampling Design

In most cases, the most cost-effective design for forest carbon inventory sampling is stratification of the landscape combined with the application of a systematic or random sampling arrangement. That is, the combined approach will complement stratification with one of the following methods:

- **Systematic sampling:** plots are placed on the landscape in a regularly-spaced fashion using a grid, such as strip sampling.<sup>15</sup> Different numbers of plots may be placed in each stratum, but the location of these plots is determined by the systematic arrangement. The start location should be randomly generated to avoid bias in the placement of sampling plots.
- **Stratified random sampling:** a pre-determined number of plots are placed randomly within each stratum. Different strata may hold different numbers of plots, with fewer plots in strata with low variability and a greater number of plots in strata with high variability.

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*In most cases, combining stratification with systematic or random sampling will be the most cost-effective design for forest carbon inventory sampling.*

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The primary benefits of these two sampling approaches are that they avoid bias in the initial placement of plots, so long as there is not an underlying geometric pattern in the occurrence of forest stands or trees. For forests where trees have been planted in rows or strips (e.g., windbreaks), the use of grid-based or even randomly distributed plots may not provide sample plots that are representative of the project area. A transect/strip-sampling approach to measuring aboveground biomass may be better-suited to these circumstances.

In any event, the plot layout should be well-distributed. If the process of randomization leads to poor plot distribution, such as most plots occurring clustered in one area or near roads,<sup>16</sup> the randomization process may have to be repeated or expanded. Random assignment of plots is not a sufficient justification for a plot layout that does not

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<sup>15</sup> The CDM sample size tool—"Calculation of the number of sample plots for measurements within A/R CDM project activities"—used to recommend this type of sampling design (based on IPCC GPG-LULUCF); however, the latest version of the tool no longer does so: <http://cdm.unfccc.int/Reference/tools/index.html>.

<sup>16</sup> It is a common practice to generate "extra" plots that may be used in the event that a pre-determined plot location is in an unsuitable location (e.g., the center of a road or stream). The project proponent should ensure that these and other plots are not visited by surveyors in lieu of others because of ease of access.

cover most of the project area or is otherwise not representative. Auditors will likely challenge results and/or require placement of additional plots to compensate for a perceived lack of representativeness in plot layout.

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*Random assignment of plots is not a sufficient justification for a plot layout that does not cover most of the project area or is otherwise not representative.*

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For natural forests, the practical differences between these two approaches can be substantial. The random assignment of plots based on a GIS or other strategy will typically require the use of Global Positioning System (GPS) units in the field by surveyors to locate plots. In contrast, the grid-based approach may allow for surveyors to measure the distance between plots by measuring their paces and utilizing compass bearings. For most projects, the use of GPS can be helpful, but the variability and imprecision of GPS signals under closed canopies has been a frequent challenge. If

random plot locations and GPS units are used, additional supporting information (e.g., bearing and distance from marked reference trees to the plot) should be recorded to help future measurement or verification teams relocate the plots.

### 3.4.3 How Many Plots Do I Need?

The number of plots necessary to achieve pre-determined precision goals is generally calculated through a series of common equations incorporating the acceptable level of error and predicted variability in measured carbon stores. This calculation is typically applied to calculate sample sizes using the aboveground live tree component. Winrock International has published a useful tool for determining the number of sample plots necessary for a forest carbon inventory; based on a spreadsheet, it is able to incorporate precision levels and basic estimates of sampling cost specified by the user.<sup>17</sup> Project developers may use this tool for CDM projects as well as other projects where the plot layout conforms to the assumptions made in the CDM tool.

These calculations assume a prior familiarity with the forest in the project area, calling for the user to enter a best guess estimate of the average value and variation of carbon storage within a particular pool and stratum. In certain cases, preliminary information about the project area or comparable forest types may already exist from previous studies or literature. If there is no such pre-existing data, a pilot study of 6-10 plots per stratum should be conducted to get a preliminary estimate of variance in each carbon pool (Pearson, Walker and Brown 2005). This calculation is repeated independently for each carbon pool of interest.

### 3.4.4 Choosing Permanent and/or Temporary Plots

The major difference between temporary and permanent plots is that temporary plots are visited once by the inventory team (and possibly again by a verifier, if they are marked in the field), whereas permanent plots are revisited over the course of future monitoring events. For plots that are solely intended to establish carbon storage at time 0 and are not planned to be used to measure growth (as in some REDD projects), there is no need to install permanent sampling plots, unless specifically required by the methodology being applied. Permanent plots are commonly recommended by other guidebooks for detecting changes in forest carbon storage over time because they are often more efficient from a statistical and sampling (including cost) perspective for demonstrating incremental changes.<sup>18</sup>

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<sup>17</sup> Available at <http://winrock.org/Ecosystems/tools.asp>.

<sup>18</sup> A larger number of temporary plots would need to be established to overcome landscape level variance in carbon stocks to statistically establish changes over time, particularly in forest types where landscape level variance is high.

In permanent plots, individual trees are identified and re-measured from one sampling event to the next. Thus, establishing a permanent sampling plot will involve tagging individual trees with identification numbers and/or mapping the location of trees within the plot for future visits. Permanent plots will also typically involve one or several plot markers identifying the plot center, its corners, or its boundaries (depending on plot shape).

When choosing to report data from permanent plots, the project must be able to demonstrate that these plots have not been treated differently than surrounding areas by forest managers and local communities that may notice plot markings such as tree tags. Otherwise, their value in predicting overall forest trends may be severely and irrevocably compromised. Examples of such issues include permanent plots being logged less heavily or being visited less by local communities than surrounding stands for gathering fuelwood or non-timber forest products.

To mitigate these risks, it is good practice to establish an extra 10-15% of permanent sampling plots in each stratum during the initial inventory to be used if a particular sample plot receives differential treatment or is lost by a natural disturbance. Periodic spot-checks using temporary plot methods surrounding the permanent plots may be the most appropriate screen to help ensure that these areas continue to be representative of the surrounding forest.

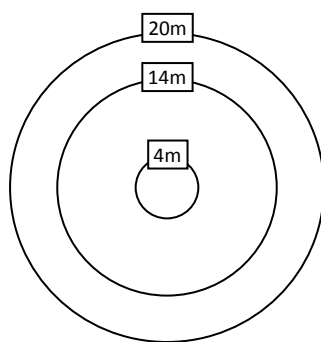
### 3.4.5 Plot Layout: Finding the Right Shape

Sampling plots generally follow three fundamental designs. Each is better suited to particular forest carbon pools and forest types, as discussed briefly below. Additional references for guidance on plot layout can be found at the end of this section.

The IPCC GPG-LULUCF states:<sup>19</sup>

The type of plots used in vegetation and forest inventories include: fixed area plots that can be nested or clustered, variable radius or point sampling plots (e.g., prism or relascope plots), or transects. It is recommended to use permanent nested sample plots containing smaller sub-units of various shapes and sizes, depending on the variables to be measured.

- **Fixed area:** The field crew measures every object meeting specified criteria within the plot area (e.g., all trees above a certain minimum diameter). Sampling plots are established with a pre-determined spatial extent, using a specific radius for circular plots, or length and width for rectangular plots. Measurements are extrapolated using an expansion factor to produce carbon stock estimates per hectare.

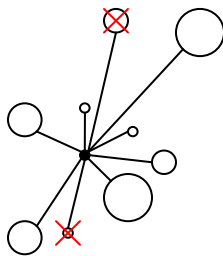


**Figure 2. Example Fixed Area Nested Sample Design**

Each plot is used to sample a different diameter range of trees, e.g. all trees from 10-30, 30-80 and > 80 cm DBH in the 4, 14, and 20m radius plots, respectively. Nested designs may also combine tree and non-tree sampling plots.

<sup>19</sup> It is important to note that IPCC GPG-LULUCF is primarily focused on detecting changes in forest carbon stocks. For project-level inventories, particularly in REDD projects where change detection is not the goal, but frequently rather the time 0 carbon stocks, the use of permanent sampling plots may be unnecessary. In addition, variable radius plot designs may also be more cost-effective than fixed area plots due to the reduced sampling effort per plot.

- **Variable radius, prism radius, or point:** In this method, a fixed angle is projected from the plot center using a prism or visual gauge. Trees that are larger in diameter than the fixed angle are measured, trees smaller than the angle are rejected. The minimum (absolute) DBH for measurement increases with distance from the plot center, so that small trees are only included when they are nearby. This method requires a clear line of sight from the central sampling point, so this sampling approach may not be viable for project forests with dense understory growth.<sup>20</sup> The tools used to collect these measurements (e.g., a relascope) produce a plot-scale volume or basal area contribution from each tree measured. This sampling approach is not suitable for measuring non-tree and downed dead wood carbon stocks.



**Figure 3. Example Variable Radius Sample**

Using a prism or visual gauge, the surveyor (black dot in diagram) stands in a central location and rotates in a circle. The surveyor identifies trees (white dots) for measurement that are equal to or larger than the fixed angle. Trees with red Xs are too small or far away to be counted “in” and measured.

- **Transects:** The field crew runs a line of specified length from one location to another and collects measurements along the line at some specified width along the line (strip sampling). This is a commonly used method for sampling downed dead wood and woody debris, but can also be used for aboveground biomass where trees within the strip are measured as in fixed area sampling. This method may also be used in combination with small grids set up at various points along the transect to measure litter and/or herbaceous vegetation.<sup>21</sup>

Most of the more detailed forest carbon inventory guides published since IPCC GPG-LULUCF have emphasized fixed area and nested plots. This focus may be due in part to the exclusion of REDD and IFM projects from the CDM: AR projects necessarily focus on detecting biomass change over time, and fixed area (permanent) plots are particularly appropriate for this purpose. The emergence of newer methodologies for other project types has re-opened the discussion on plot designs such as variable radius sampling, which, for example, has found widespread application in the broader forest inventory community, including national inventory authorities and the timber industry.

In many circumstances, variable radius sampling designs are more cost-effective for carbon inventories, particularly when the inventory is primarily focused on measurements of aboveground biomass, as most are. It can be a much quicker and less costly sampling method compared to fixed area plots because only a fraction of the trees present are sampled and no outer limit of plots needs to be measured. The variable radius approach has commonly been used with temporary plots to rapidly estimate basal area and merchantable volume for timber surveys.

Table A1 (see Appendix) indicates which methodologies have specific plot layout criteria. Newer VCS methodologies—such as Ecotrust’s IFM methodology (VM0003) and Avoided Deforestation Partners REDD Modules (VM0007)—are among the first forest carbon methodologies to provide an explicit mention of variable radius sampling. Most of the methodologies surveyed do not explicitly mention plot shape, but most imply, through the

<sup>20</sup> This method preferentially samples larger diameter trees. This potential bias is worth noting, but is not necessarily problematic in that it focuses sampling efforts on larger trees where most of the aboveground carbon is stored without overestimating stand-level carbon stocks.

<sup>21</sup> For a more detailed treatment of the procedures and statistical considerations for strip sampling, see Iles (2003).

phrasing “plot area” in many equations, that fixed area plots are the only type of plots the methodology authors were considering.

Looking forward, project developers should consider using variable radius plots in circumstances where measuring incremental change in biomass over time is not the primary goal. Although variable radius plots can also technically be used for detecting change over time, they are more frequently used to provide rapid snapshots of forest volume at one point in time.

#### Box 10. Additional Guidance on Plot Design and Sampling

The most commonly cited guidebook for forest carbon projects, which includes guidance on fixed area plots and sampling considerations, is:

- Pearson, Timothy, Sarah Walker, and Sandra Brown. *Sourcebook for Land Use, Land-Use Change and Forestry Projects*. Winrock International and World Bank BioCarbon Fund, 2005. Available at: [http://www.winrock.org/ecosystems/files/winrock-biocarbon\\_fund\\_sourcebook-compressed.pdf](http://www.winrock.org/ecosystems/files/winrock-biocarbon_fund_sourcebook-compressed.pdf).

Further discussion of plot layout and sampling considerations directed towards forest carbon measurement can be found in:

- Pearson, Timothy R.H., Sandra L. Brown, and Richard A. Birdsey. *Measurement Guidelines for the Sequestration of Forest Carbon*. GTR-NRS-18, Newtown Square, PA: USDA Forest Service, 2007. Available at: <http://www.nrs.fs.fed.us/pubs/3292>.

For textbook documentation of the methods and considerations for forest measurement (not focused on carbon), consult:

- Avery, T., and H. Burkhardt. *Forest Measurements, Fifth Ed.* New York: McGraw-Hill, 2002.

Detailed treatment of additional practical approaches to forest sampling, including a good discussion of variable radius sampling and other techniques can be found in:

- Iles, Kim. *A sampler of inventory topics: a practical discussion for resource samplers, concentrating on forest inventory techniques*. Nanaimo, Canada: Kim Iles & Associates, 2003.

## 4. Quantifying Stock Changes and Emissions

The essential goal of forest carbon projects is the achievement of a net positive carbon balance for the project area over time, either through increased carbon sequestration or reduced carbon loss. Stock change measurement and related monitoring activities are the primary vehicles for quantifying these benefits. This section first describes the general scope of monitoring activities across project types and then moves into the timing of monitoring activities in project development and evaluation. The next section describes the specific monitoring activities and measurements required for documenting changes in carbon storage before concluding with a description of leakage monitoring outside the project area.

### 4.1 The Logic of Monitoring

Documenting the gains and losses of carbon over time follows different accounting paradigms depending on the project type, as described earlier in this chapter. In addition, the specific pools and emissions sources to be monitored vary between methodologies and project types, as does the frequency with which field measurements must be recollected.

For AR projects and some IFM projects, the emphasis placed on incremental biomass growth through stock change accounting most often means that monitoring activities for these projects will be synonymous with a repetition of the inventory process and should, therefore, largely follow the same SOPs developed for calculating time 0 stocks. All pools chosen for measurement in the time 0 inventory will be re-measured over time to estimate the net carbon sequestration provided by the project.

For most REDD projects, however, the role of the field inventory is reduced dramatically after the calculation of time 0 carbon stocks. In general, the monitoring activities for REDD projects involve documenting land area changes (where the change in stocks measured by inventory plots will be multiplied by the area undergoing each type of land use or land-use change). Unless a REDD project intends to account for incremental growth in conserved plots, the remaining monitoring activities will largely consist of spot-checking deforested and degraded plots to confirm the rates of carbon loss (emission factors) used for flux-based accounting. Methods for detecting and quantifying land area change are discussed in more detail in the REDD Guidance of this series.

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*Monitoring project performance can also communicate the successes and challenges in realizing project goals to communities, staff, investors, and other interested parties.*

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## 4.2 Monitoring in the Project Cycle

The monitoring activities and planning described here will occur at several discrete times throughout the project cycle, typically every five years. The development of the monitoring plan should be completed during the planning/design phase, along with the time 0 inventory planning, and included in the Project Design Document. The actual monitoring activities will occur during the implementation phase of the project, given that they primarily measure success of project activities being implemented.

### 4.2.1 Creating a Monitoring Plan

A monitoring plan describes the procedures that will be applied over time to identify and quantify changes in project areas over time. The plan should include: the methods for determining and updating the project boundaries, stratification, and sampling design; the pools to be measured; and the duration of the project and frequency of monitoring events. For some projects, this may include monitoring areas both inside and outside the project boundary. A monitoring plan should also document the corresponding capacity in terms of staffing and other resources that will be necessary to ensure the plan can be followed.

### 4.2.2 Monitoring Project Implementation

Several VCS methodologies surveyed here describe monitoring project implementation as simply documenting the actual emissions and sequestration of GHGs from project activities. Other VCS and CDM methodologies require more detailed documentation. This chapter advocates a broader conception of project implementation monitoring because this encourages the project developer to gather information not only to demonstrate to external reviewers that the project is complying with formal requirements. Instead, monitoring of project performance can also communicate the successes and challenges in realizing the goals of the project to communities, staff, investors, and other interested parties, and can become an effective tool for adaptive project design and management (see Step-by-Step Overview).

In addition to quantifying the changes in carbon stocks and emissions, some CDM and VCS methodologies (e.g., ACM0001) require<sup>22</sup> that “the forest planting and management plan, together with a record of the plan as actually implemented during the project shall be available for validation or verification.” Having a forest management plan is a critical component for establishing benchmarks for project evaluation. Beyond carbon sequestration and emissions, the performance of the project along other metrics, including timber and other yields, community engagement, biodiversity and social impacts, and financial performance should also be part of the monitoring plan.

### 4.2.3 Frequency of Monitoring Efforts

Unique monitoring requirements are sometimes specified by the individual CDM and VCS methodologies. Where this is not the case, projects should plan to complete monitoring field measurements and calculations at least prior to each scheduled field verification event.

Methodologies with monitoring specifications will define the maximum interval for repeated monitoring and reporting events for relevant pools (typically every 5 to 10 years). Some monitoring may be required on an annual basis (e.g., natural and human disturbance) while others may take place in longer intervals, and should be specified by the methodology (e.g., every five years for aboveground biomass or longer for soil organic carbon).

It is important to note that even if no verification event is planned for several years, projects must comply with any specific monitoring intervals required by the standards or methodology applied. For example, even if a project is not planning to undergo its first verification for 10 years, many methodologies specify that natural disturbances must be monitored and reported every year, and the project will need to conduct and document the relevant measurements as specified by the methodology. When the project eventually comes to verification, the auditor will expect to see documentation that monitoring was conducted as required by the methodology.

For both VCS and CDM the timing of the first verification is at the discretion of the project proponent. For AR projects, this discretion allows the project proponent to allow planted trees sufficient time to grow to ensure the first measurement campaign is worth the effort. Verification intervals are then fixed at five years under the CDM (for AR projects) but are more flexible under the VCS. Once the first verification has been completed, both VCS and CDM projects are expected to undergo verification at least every five years, although this is not a hard requirement under the VCS.<sup>23</sup>

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*For both VCS and CDM, the timing of the first verification is at the discretion of the project proponent.*

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More frequent monitoring may be advisable to keep track of project performance, as well as to help decide when renewed verification becomes economically attractive. The interval between full monitoring (and verification) events can often be adjusted to ensure that costs incurred will be justified by a sufficient volume of carbon credits to be generated (see Business Guidance and Step-by-Step Overview).

Future inventories may be conducted in a rolling manner (i.e., a portion of the plots measured in year 1, with an equal portion measured in year 2, completing the cycle every before

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<sup>22</sup> This requirement is also repeated in several other CDM methodologies as well as in VCS methodologies by Ecotrust (VM0003) and Face the Future (VM0005). Similar considerations are also offered in the proposed FAS and BioCarbon Fund VCS REDD methodologies.

<sup>23</sup> Instead, VCS utilizes an incentive system whereby credits held in a project's buffer pool are periodically released following repeated verification reports. Failure to repeat verifications within five-year intervals may result in (reversible) cancellation of credits in the project's buffer pool.



the next verification) or completed within discrete field campaigns (i.e., all plots surveyed in one year). Rolling inventories may be better suited for very large land areas with too many plots to feasibly measure by project staff each year; however, this will require good planning and a robust QA/QC framework to ensure that all plots are updated within the required timeframes and to ensure consistency from year to year.

#### 4.2.4 Revisiting Stratification

In general, the inventory map and stratification layer(s) should be updated after new field measurements are collected, if errors are discovered, or when major disturbances occur. Updating the strata for a forest area will ensure that the sampling strategy remains cost-effective and meets precision targets. As ongoing measurements are collected, individual plots may be abandoned and strata may be further divided or combined so long as precision, representativeness, and other QA/QC requirements are still met by the remaining active sampling plots. All changes to strata boundaries should be justified and documented for potential review by auditors.

### 4.3 Quantifying Carbon Stock Changes in the Project Area

#### 4.3.1 Quantifying Forest Growth

Quantifying forest growth in AR projects has most commonly been done through periodically re-measuring trees in permanent plots. Temporary plots may also be used to provide estimates of forest growth across each stratum; however, detecting changes in forest growth with the same precision will usually require more – or larger – plots. Other pools such as litter, understory vegetation, downed dead wood, and soil may need to be sampled in different locations in or around permanent plots during successive sampling events if the methodology being used requires destructive sampling techniques.

Quantifying forest growth in this manner is obviously the key rationale for AR projects and many IFM projects. REDD projects using a methodology that allows for accounting incremental forest growth in the project area can follow the same approach.

#### 4.3.2 Quantifying Biomass Removals and Disturbances

Substantial disturbances from human and natural causes should be documented, usually on an annual basis. Monitoring should include both planned and unplanned human disturbances, and the methods used for quantification should be specified in the monitoring plan. The major disturbances that should be considered for monitoring include planned and unplanned biomass removals, as well as tree mortality and biomass loss from natural disturbances such as wildfire, storm damage, and pest and disease outbreaks.

In general, monitoring of natural disturbances should include quantification of both the area affected by the disturbance and the biomass lost per area. The level of disturbance or biomass loss necessary to require documentation (i.e., confirm materiality) with a unique monitoring report is not specified in any individual CDM or VCS methodologies. However, VCS's most recent standards documentation (version 3.0) defines the threshold for "loss events" that must be accounted for as "any event that results in a loss of more than 5% of carbon stocks in pools



included in the project boundary that is not planned for in the project description.”<sup>24</sup> Project proponents should therefore be prepared to document any disturbances that are likely to produce a change of this magnitude.<sup>25</sup>

The risk of impermanence in forest carbon was addressed under the CDM through the use of temporary credits. Under this standard, if natural disturbances led to carbon stock losses, this would inhibit the re-certification of temporary credits. For other standards, the buffer pool concept has become the most popular strategy for addressing risks to forest carbon permanence. Post-disturbance monitoring in forest carbon projects will determine the volume of credits that may be cancelled from the buffer pool to cover the unexpected emissions from the project at the time of subsequent verification events.

Depending on the scale of the disturbance, project developers may need to remodel their baseline with new starting levels and, if carbon stock losses are particularly dramatic, there may even be a need to terminate the project. Policies regarding buffer pool use under VCS are provided in the VCS Agriculture, Forestry, and Other Land Use (AFOLU) Requirements.<sup>26</sup>

Areas that are affected by disturbance may also require installation of additional temporary or permanent plots to continue meeting the requirements for inventory precision, and even the introduction of a new stratum could be

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*The monitoring plan should address both planned and unplanned disturbances and should specify quantification methods.*

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justified. Field measurements should ideally be conducted soon after disturbance events and should continue in the future to document any recovery of biomass stocks.

For projects implemented under VCS, the results of disturbance monitoring may also have implications on the non-permanence risk assessment for the project’s buffer discount. Depending on the situation, findings could indicate that certain risks are indeed real and have not been mitigated effectively, or that disturbance events have been picked up early and effective response strategies devised. For

more consideration of these risk assessment issues, see the AR, REDD, and Business Guidance documents.

### **Carbon Stock Changes from Planned Timber Harvest**

Some methodologies are restricted in their applicability regarding expected legal and/or illegal harvesting. If legal harvesting is expected to occur in the project area in the future, then project developers should make sure to choose a methodology that allows for this.

Under an applicable methodology, the accounting for timber harvesting will commonly include either an indirect assessment of the scale of biomass removal, the use of harvest records, or direct field measurements. However, the actual measurement requirements for reporting timber harvesting are not usually explicitly specified. Most methodologies simply provide equations indicating that the volume of extracted biomass must be reported, taking into account the entire tree (i.e. not simply timber volume). If dead wood accounting is employed by the project, the accounting procedures for harvest volumes should be the same; some of the carbon transferred from the live

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<sup>24</sup> This definition does not address whether loss events must occur in single occurrences, or whether multiple separate smaller losses over time from the same source (e.g., repeated small-scale illegal harvests) must also be accounted for, so project proponents should consult with VCS officials if they believe their project is being affected by losses of this nature.

<sup>25</sup> It is also worth noting that natural disturbances that would likely have occurred in the business-as-usual/baseline case do not necessarily result in penalties to the project, but may require a recalculation of the baseline to account for the disturbance.

<sup>26</sup> The program documents for VCS Version 3, applicable as of March 2011, are available at <http://v-c-s.org/program-documents>.

biomass pool to the dead wood pool associated with harvesting (i.e., harvest residues) should be captured in ongoing sampling of the dead wood pool. When considering harvesting removals, some methodologies also require the accounting for trees damaged or killed along skid trails.

Field-based quantification of tree harvesting must be complemented by before-and-after measurements of harvested plots, or alternatively through a simpler BEF approach where the merchantable volume documented in harvested records is scaled up to whole-tree carbon stock estimates.

Carbon accounting questions related to long-lived wood products created by timber harvesting are discussed further below.

### Unplanned Carbon Losses

Unplanned carbon losses (a subset of forest degradation) from activities such as illegal timber harvesting or fuelwood removals should always be monitored if the carbon losses are likely to be material. The specific measurement techniques used may differ between baseline calculations and monitoring events, and certain methodologies apply eligibility restrictions based on the presence of illegal logging degradation or fuelwood gathering, so project developers should carefully review the applicability and measurement requirements for the chosen methodology. In addition to monitoring and baseline calculations, there may also be unique specifications for quantifying leakage (discussed again briefly in Section 4.4 below).<sup>27</sup> In general, project developers will need to identify the land area undergoing degradation through field monitoring or interviews with local communities and perform some level of field visit to estimate the emissions associated with the degradation activity. Identifying areas where unsustainable fuelwood extraction or other forest degradation has occurred may help to stratify the forest area for additional sampling purposes.

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*Discrete and significant disturbances that may produce a loss of carbon above 5% from the pools accounted in the project should receive specific monitoring attention and reporting.*

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Quantifiable extracted volumes from illegally logged areas will often not be directly apparent from the disturbed area alone. The removed volume will generally be estimated by either measuring stumps in logged areas or by comparing survey plots in undisturbed areas belonging to the same stratum as the harvested area, an approximation of before-and-after measurement.

The quantification of emissions from fuelwood use is handled differently between current methodologies. The Avoided Deforestation Partners REDD Methodology's module for quantifying fuelwood degradation baselines (VMD0008 BL-DFW) requires interviews with local fuelwood gatherers (known as participatory rural appraisals, or PRA's) to estimate annual per capita fuelwood use. These PRA's are combined with field measurement to translate the fuelwood use reported from interviews into GHG emissions estimates. Estimates of tree volume loss through degradation in this methodology are calculated by measuring the diameters of stumps in degraded stands. These emission factors must be updated as part of the baseline revision process this methodology requires every 10 years. Distinct from the baseline calculations, however, monitoring under this methodology (as described in modules VMD0012 LK-DFW and VMD0015 M-MON), requires PRAs to be completed every two years to estimate actual

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<sup>27</sup> A critical distinction should be made between accounting for degradation versus deforestation, as the two are treated differently by current methodologies. For example, the Avoided Deforestation Partner's VCS REDD methodology modules dealing with degradation currently apply only for mitigation of fuelwood gathering as a degradation driver. This module explicitly precludes crediting avoided emissions from illegal harvesting that degrades a forest without leading to land-use change. At the same time, although projects cannot claim avoided degradation benefits from preventing illegal harvesting, they are expected to account for illegal harvesting emissions that occur with project monitoring. See the REDD Guidance of this series for further discussion of these applicability and accounting distinctions.

fuelwood extraction. Where PRA's reveal degradation is likely, systematic field sampling must be implemented and repeated at least every five years.

The Wildlife Works VCS REDD Methodology (VM0009) focuses on deforestation as the ultimate land-use fate, and conservatively excludes accounting for avoided degradation in the baseline scenario. Nevertheless, degradation is still measured and accounted for in ongoing monitoring of project emissions and leakage. In contrast to the ADP VCS REDD Modules, however, field measurements under the Wildlife Works Methodology are greatly simplified. PRA's are optional under this methodology and field plots must be assessed at least once every five years to be categorized as 20%, 40%, 60%, 80% degraded or 100% degraded (deforested). There is no specification of physical field measurement collected in the degraded areas to make this categorical assessment.

### **Carbon Accumulation in Harvested Wood Products**

All CDM methodologies (which also currently comprise the only approved AR methodologies for use under VCS as well) conservatively assume that biomass removed from the project area is re-emitted immediately back to the atmosphere as carbon dioxide. Most other methodologies developed by standards outside the CDM allow or require accounting for carbon storage in wood products in baseline and leakage calculations using decay factors to estimate the volume of carbon remaining in 'long-term' harvested wood products after 100 years. In general, it is worth noting that most methodologies do not enable increased production of wood products in the project case as an emissions reductions strategy.

In terms of monitoring where wood products accounting is allowed, the only major distinction in variables collected during harvest is that the volume extracted needs to be broken down by species or at least into potential wood product classes. In many circumstances, harvest records may be sufficient for this data source, but records from a wood processing facility alone may not be sufficient. By differentiating harvested volume into peelers, saw logs, posts and poles, pulpwood, etc., the factors for different product life cycles will then be applied. In general, these decay factors are based upon estimates reported in the scientific literature. Most methodologies with international scope use decay factors from Winjum, Brown and Schlamadinger (1998); decay factors for the United States (including use in other standards beyond VCS) are often based on the US Department of Energy's 1605(b) Program.

### **Emissions from Fire and Other Natural Disturbances**

The consideration of specific post-disturbance monitoring following a natural disturbance in addition to regularly scheduled monitoring events is largely a factor of the scale of the disturbance. Discrete and significant disturbances that may produce a loss of carbon above 5% from the pools accounted in the project should receive specific monitoring attention and reporting. Less discrete disturbances such as pest damage, wind-throw, and drought-induced mortality may be captured in regular carbon stock change detection and do not require additional monitoring reporting as with catastrophic disturbances.

For wildfires, storm, and pest damage, pre-disturbance biomass estimates from the plot(s) or strata burned, or from plots in the same strata that have not burned may be coupled with post-disturbance sampling to estimate the area and biomass losses from the disturbance event. Depending upon the carbon pools accounted for in the project and the scale of the disturbance, the reporting of carbon losses may or may not ultimately yield a negative emissions balance for the year or crediting period.

In cases where the disturbance would likely have occurred under the business-as-usual scenario, project developers may be required to revise their baseline and risk profile, but typically will not face penalties (although credits may still be put on hold or cancelled from the buffer pool to mitigate any risks of reversals).

### Box 11. Additional Guidance on Natural Disturbance Monitoring

The VCS methodology developed by Carbon Planet (VM0011) “Methodology for Improved Forest Management – Logged to Protected Forest: Calculating GHG Benefits from Preventing Planned Degradation” provides the most comprehensive discussion of post-disturbance measurement and monitoring of any reviewed here, including strategies for post-disturbance monitoring of regrowth. Available at: <http://v-c-s.org/methodologies/VM0011>.

For further information on how VCS handles loss reports and potential reversals, see “VCS Guidance: Accounting for Loss Events” at:

<http://v-c-s.org/sites/v-c-s.org/files/VCS%20Guidance%2C%20Buffer%20and%20Loss%20Examples.pdf>.

Further discussion and guidance regarding the use of buffer pools can also be found in the Business, AR, and REDD guidance documents.

## 4.4 Monitoring Activity-Shifting Leakage

When the project’s implementation results in leakage from “activity shifting” (i.e., measurable GHG emission increases outside the project boundaries due to displacement of deforestation and degradation agents directly attributable to project activities), monitoring the scale of this leakage will be required for most projects, as long as leakage emissions are found to be significant.<sup>28</sup> For the methodologies surveyed here, the calculation of leakage due to activity shifting (e.g., displaced cropland conversion, pasture conversion, timber harvesting, road-building, or fuelwood gathering) is typically assessed by determining the area affected and multiplying by emissions factors corresponding to the particular activity that was shifted to outside the project boundary. Land-area change detection is discussed in more detail in the REDD Guidance.

Recent REDD methodologies under the VCS include the use of “leakage belts” to monitor the displacement of deforestation, forest degradation, and other sources of biomass loss and emissions that are geographically constrained and therefore likely to occur surrounding the project area. In all the methodologies surveyed here, the ongoing monitoring of activity-shifting leakage is based primarily on land area change detection (except for the case of displaced fuelwood gathering).

Methodologies that require field measurement include measurement of “before” and “after” plots for a matrix of potential land-use transitions (described in detail by Terra Global Capital’s VCS REDD Methodology, VM0006), which are then used to create conversion factors that will be applied to the areas undergoing each type of transition (e.g., from non-disturbed forest to forest degraded through fuelwood collection). In general, individual instances of deforestation and degradation outside the project area do not need to be coupled with direct field measurements apart from any updating of emissions factors that may be required by the methodology. All approved VCS REDD methodologies require updates to these factors every five years.

The IFM methodologies from Ecotrust (VM0003) and Face the Future (VM0005) have project eligibility criteria that preclude projects with significant levels of fuelwood gathering, litter removals, or other biomass removals from

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<sup>28</sup> There are several different types of leakage that project proponents need to consider when developing forest projects. The primary types of leakage often discussed are activity-shifting leakage and market leakage. Since activity-shifting leakage may be closely related to field inventory procedures, it is discussed briefly in this chapter. For further discussion of market and other leakage considerations, please refer to the REDD and AR guidance documents.

forests in the baseline. Thus, no field measurements will be required for the leakage accounting mandated under these methodologies.

For AR projects, displacement of grazing or agricultural activities is generally dealt with by monitoring the land area affected by agriculture outside the project area prior to and shortly after the implementation of the project activities. For example, CDM AR-AM0004 requires documented and verifiable periodic interviews of previous landowners during the first five years of project implementation to assess whether they have undertaken these activities on additional properties.

### Box 12. Resources for Leakage Calculations

Since both operational IFM methodologies under VCS do not currently address activity-shifting leakage, the only current guidance for this type of monitoring is currently provided by methodologies and tools for AR and REDD projects. Each REDD Methodology under the VCS presents a comparable, but slightly different approach for measuring and monitoring changes in forest carbon stocks associated with leakage activities being monitored. The methodologies from Avoided Deforestation Partners (VM0007), Wildlife Works Carbon (VM0009) and Terra Global Capital (VM0006) can be found at <http://v-c-s.org>.

Under the CDM, the primary tool for assessing leakage due to agricultural and grazing activities is the tool for Estimation of the increase in GHG emissions attributable to displacement of pre-project agricultural activities in A/R CDM project activity. The most recent version of this tool can be found at <http://cdm.unfccc.int/methodologies/ARmethodologies/approved>.

## 5. Conclusions

Forest inventory practices are among the most well-established aspects involved in forest carbon project development. The implementation of particular forest inventory techniques varies across methodologies, with most historically emphasizing fixed area permanent plots. The emergence of methodologies governing IFM and REDD projects in recent years has re-opened the possibility of using temporary and variable radius plots, which have also long been used in many national forest inventory programs and private timber industry surveys.

The choice of methods used in a forest inventory should always strive to follow good practice guidance provided by the IPCC. Sticking to the principles of conservativeness and verifiability will also help the inventory planner navigate the array of options available for conducting a forest carbon inventory. Although many techniques for the inventory will be prescribed and constrained by the chosen methodology, considerable expertise in the planning and execution of the inventory will still be required.

Inventory and monitoring activities will typically occur at defined intervals over the course of a project life, in both the planning and implementation phases of the project cycle. Effectively integrating the full inventory and monitoring expectations early on in the project planning phase can be significantly aided by the completion of a brief, pre-inventory sampling process. The abbreviated sampling of the project area will provide basic information about the project area's forest carbon stocks and their variability that may not be available in the scientific literature.

This chapter has endeavored to highlight opportunities and strategies for cost-effective inventory efforts. However, as the technology for detecting forest carbon stocks and changes advances, particularly in the realm of remote sensing, much of this guidance will need to be viewed in the light of forthcoming scientific literature and methodology and standard guidance.

In closing, it should again be stressed that the planning for inventory assessment and monitoring is an opportunity to advance a project's diverse goals. Striving for coordinated planning among diverse monitoring interests - such as biodiversity and social impact assessments, financial performance, and more - should be a critical consideration. The inventory should not be viewed as an isolated or independent suite of activities in the project cycle; instead, well-designed inventories and monitoring plans can create synergies with other project evaluation activities. Planners across the different scopes of project development should all be involved in forging a project management and monitoring plan that leverages the contributions provided by each stakeholder and team member, including local communities. While an inventory may seem to be a well-defined means to quantify how much of a climate impact your project has made, its role in ensuring the longer-term viability of the project often provides a venue for creative planning and reflection.

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# Appendix

Table A1. Inventory Requirements Specified in CDM Forest Carbon Methodologies

					Carbon Pools Included						QA/QC		
Methodology	Permanent Plots?	Fixed Area Plots ?	Specific Plot Layout?	Allometric Equations Only?	Above-grnd Biomass	Below-grnd Biomass	Products	Lying Dead wood	Mineral Soil	Forest Floor (litter + duff)	Confidence Interval (%)	Error (% of mean)	QA/QC Guidance
CDM AR													
AR-ACM0001, v4	Y	-	Y	N	+ (m)	+ (c)	x	~ (m)	~ (c)	~ (m)	95	10	-
AR-ACM0002, v1	Y	-	Y	N	+ (m)	+ (c)	x	x	~ (c)	x	95	10	-
AR-AM0002, v3	-	-	Y	N	+ (m)	+ (c)	x	+ (m)	+ (m)	+ (m)	90	10	-
AR-AM0004, v4	Y	Y	Y	N	+ (m)	+ (c)	x	x	x	x	90	10	Y
AR-AM0005, v4	Y	-	-	N	+ (m)	+ (c)	x	x	x	x	90	10	-
AR-AM0006, v3	Y	Y	Y	N	+ (m)	+ (c)	x	x	+ (m)	x	90	10	-
AR-AM0007, v5	Y	-	-	N	+ (m)	+ (c)	x	~ (m)	~ (c)	~ (m)	95	10	-
AR-AM0009, v4	Y	-	-	N	+ (m)	+ (c)	x	~ (m)	~ (c)	~ (m)	95	10	-
AR-AM0010, v4	-	Y	Y	N	+ (m)	+ (c)	x	x	x	x	90	10	Y
AR-AM0011, v1	Y	Y	-	N	+ (m)	+ (c)	x	x	x	x	90	10	Y
AR-AM0012, v1	Y	-	-	N	+ (m)	+ (c)	x	x	~ (c)	x	90	10	-
AR-AM0013, v1	-	-	-	N	+ (m)	+ (c)	x	~ (m/c)	~ (c)	~ (m/c)	90	10	-
CDM Small-Scale AR													
AR-AMS0001	Y	-	-	N	+ (m)	+ (c)	x	x	x	x	95	10	-
AR-AMS0002	Y	-	-	N	+ (m)	+ (c)	x	x	x	x	95	10	-
AR-AMS0003	Y	-	-	N	+ (m)	+ (c)	x	x	x	x	95	10	-
AR-AMS0004	Y	Y	Y	N	+ (m)	+ (c)	x	x	x	x	90	10	-
AR-AMS0005	Y	Y	-	N	+ (m)	+ (c)	x	x	x	x	90	10	-
AR-AMS0006	Y	Y	Y	N	+ (m)	+ (c)	x	x	x	x	90	10	-
AR-AMS0007	-	-	-	N	+ (m)	+ (c)	x	x	x	x	90	10	-
Codes: Y = explicit requirement; N = explicitly not required; - = no explicit specifications; + = measurement required; ~ = measurement optional, potential significant testing; x = measurement excluded; (m) = field measurement required; (c) = calculation-based estimate, field measurement not required for all samples.													

Table A1 (continued). Inventory Requirements Specified in VCS Forest Carbon Methodologies

					Carbon Pools Included						QA/QC		
Methodology	Permanent Plots?	Fixed Area Plots ?	Specific Plot Layout?	Allometric Equations Only?	Above-grnd Biomass	Below-grnd Biomass	Products	Lying Dead wood	Mineral Soil	Forest Floor (litter + duff)	Confidence Interval (%)	Error (% of mean)	QA/QC Guidance
<b>VCS REDD</b>													
VM0004 (Infinite Earth)	N (exc. growth)	-	N	N	+(m/c)	×	+(m/c)	×	Peat (m)	×	90	10	Y
VM0006 (Terra Global Capital)	Y	-	Y	N	+(m)	+(c)	+(m/c)	+(m)	×	×	95	15	Y
VM0007 (Avoided Deforestation Partners)	-	N	N	Y	+(m)	~(c)	~(m/c)	~(m)	~(m)	~(m)	95	15	-
VM0009 (Wildlife Works Carbon)	-	Y	N	Y	+(m)	~(c)	+(c)	~(m)	~(m)	×	95	15	Y
Fundação Amazonas Sustentável (2008)*	N	-	Y	N	+(m)	~(c)	~(m/c)	~(m)	~(m)	~(m)	95	10	-
BioCarbon Fund (2008)*	N	-	Y	N	+(m)	~(c)	~(m/c)	~(m)	~(m)	~(m)	95	10	-
<b>VCS IFM</b>													
VM0003 (Ecotrust)	N	N	-	N	+(m)	+(c)	~(m/c)	~(m)	×	×	90	10	-
VM0005 (Face the Future)	Y	-	-	N	+(m)	~(c)	+(m/c)	+(m)	×	×	95	10	Y
VM0010 (GreenCollar Climate Solutions)	-	-	-	Y	+(m)	×	+(m/c)	+(m)	×	×	95	15	-
VM0011 (Carbon Planet Ltd)	Y	Y	N	N	+(m)	×	+(m/c)	+(m)	×	×	95	10	Y
VM0012 (3GreenTree & ERA)	majority	Y	N	Y	+(m)	+(c)	+(m/c)	+(m)	×	×	95	10	Y
Carbon Credit Corp (2010)*	N	N	N	N	+(m)	~(c)	+(m/c)	+(m)	~(m)	×	90	10	-
Terra Global Capital, Grp Projects (2010)*	Y	-	Y	N	+(m)	+(c)	+(m/c)	+(m)	~(m)	×	90	10	Y
<p>* Methodologies with an asterisk (*) had not completed validation under VCS as of May 2011 and may be subject to change.</p> <p><b>Codes:</b> Y = explicit requirement; N = explicitly not required; - = no explicit specifications; + = measurement required; ~ = measurement optional, potential significant testing; × = measurement excluded; (m) = field measurement required; (c) = calculation-based estimate, field measurement not required for all samples.</p>													

# Glossary

For CDM projects, readers may wish to refer to the official definitions provided in the CDM Glossary of Terms, available at: [http://cdm.unfccc.int/Reference/Guidclarif/glos\\_CDM.pdf](http://cdm.unfccc.int/Reference/Guidclarif/glos_CDM.pdf).

VCS also provides standard Program Definitions, which are available at: <http://www.v-c-s.org/sites/v-c-s.org/files/Program%20Definitions%2C%20v3.0.pdf>.

**Additionality** – The principle of carbon additionality is that a carbon project should only be able to earn credits if the GHG benefits would not have occurred without the revenue (or expected revenue) of carbon credits. The same principle of additionality can be applied to social and biodiversity benefits.

**Attribution** – The isolation and accurate estimation of the particular contribution of an intervention to an outcome, demonstrating that causality runs from the intervention to the outcome. That is, attribution demonstrates that benefits claimed by the project (usually *co-benefits*) have been caused by the project and not another phenomenon.

**Baseline** – See *reference scenario*.

**Biodiversity target** – Biodiversity features which the project will target in its efforts to achieve net positive impacts on biodiversity. These will usually comprise High Conservation Values.

**Causal model** – See *theory of change*.

**Co-benefits** – Benefits generated by a forest carbon project beyond GHG benefits, especially those relating to social, economic, and biodiversity impacts.

**Control** – In the context of impact assessment for forest carbon projects, an area that does not experience project interventions but is otherwise similar to the project area. Controls are used to monitor the reference scenario and to demonstrate the attribution of outcomes and impacts to the project.

**Counterfactual** – The outcome that would have happened had there been no intervention or project – i.e., the final outcome of the reference scenario.

**Evaluation** – The systematic and objective assessment of an on-going or completed project, program or policy, and its design, implementation, and results.

**GHG benefits** – Any emissions reductions from reducing carbon losses or emission removals from enhanced carbon sequestration due to the forest carbon project activities.

**Impact** – The positive and negative, primary and secondary, short- and long-term effects of a forest carbon project. Impacts may be direct or indirect, intended or unintended. Impacts result from a chain of inputs, outputs, and outcomes.

**Indicator** – A measurable variable that reflects, to some degree, a specific monitoring information need, such as the status of a target, change in a threat, or progress toward an objective.

**Inputs** – The financial, human, and material resources used for a forest carbon project. Most relevant in discussion of outputs, outcomes, and impacts.

**Leakage** – The geographical displacement of GHG emissions – or social, economic, or biodiversity impacts – that occurs as a result of a forest carbon project outside of the forest carbon area. Leakage assessments must consider adjacent areas as well as areas outside of the project zone.

**Measurement, Reporting, and Verification System** – A national, subnational, or project-level set of processes and institutions that ensure reliable assessment of GHG benefits associated with real and measurable emission reductions and enhancement of carbon stocks.

**Methodology** – An approved set of procedures for describing project activities and estimating and monitoring GHG emissions.

**Monitoring** – A continuing process that uses systematic collection of data on specified indicators to provide indications of the extent to which objectives are being achieved.

**Multiple-benefit projects** – Projects that generate sufficient environmental and social co-benefits, in addition to GHG benefits.

**Outcomes** – The likely or achieved short-term and medium-term effects of an intervention’s *outputs*.

**Outputs** – The products, capital goods, and services that result from a forest carbon project.

**Project area** – The land within the carbon project boundary and under the control of the project proponent. (The CCB Standards use distinct language for *project area* and *project zone*.)

**Project developer** – The individual or organization responsible for the technical development of the project, including the development of the PDD, the assessment of social and biodiversity impacts, monitoring and evaluation, etc. Although the term does not necessarily describe a commercial entity, it often refers to an external company that is contracted to do work on the ground.

**Project Design Document** – A precise project description that serves as the basis of project evaluation by a carbon standard, commonly abbreviated to PDD. (Alternatively, VCS calls this the “project description,” or PD)

**Project participant** – Under the CDM, a Party (national government) or an entity (public and/or private) authorized by a Party to participate in the CDM, with exclusive rights to determine the distribution of CERs – equivalent to *project proponent* under the VCS. In the voluntary market, project participant is used more loosely to describe any individual or organization directly involved in project implementation.

**Project proponent** – A legal entity under the VCS defined as the “individual or organization that has overall control and responsibility for the project.” There may be more than one project proponent for a given project. Carbon aggregators and buyers cannot be project proponents unless they have the right to all credits to be generated from a project.

**Project zone** – The project area plus adjacent land, within the boundaries of adjacent communities, which may be affected by the project. (The CCB Standards use distinct language for *project area* and *project zone*.)

**REDD** – A system that creates incentives and allocates emissions reductions from reducing emissions from deforestation and forest degradation.

**REDD+** – A system that creates incentives and allocates emissions reductions from the following activities: (a) reducing emissions from deforestation; (b) reducing emissions from forest degradation; (c) conservation of forest carbon stocks; (d) sustainable management of forests; and (e) enhancement of forest carbon stocks.

**Reference scenario** – An estimated prediction of what will happen in a given area without the project. Reference scenarios may cover land use patterns, forest conditions, social conditions, and/or biodiversity characteristics. Also called the “business-as-usual scenario” and the “baseline.”

**Starting conditions** – The conditions at the beginning of a project intervention. Also called “original conditions” in the CCB Standards and sometimes referred to as the “baseline” in the field of impact assessment. This can, however, lead to confusion, considering that CCB Standards and carbon standards use the same term to describe the “reference scenario” of a forest carbon project.

**Theory of change** – The hypothesis, as developed by the project design team, of how the project aims to achieve its intended goals and objectives, including social and biodiversity objectives. This is sometimes referred to as the *causal model*.



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