A Global Benchmark for Carbon

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Methodology for Avoided Mosaic Deforestation of Tropical Forests

About Wildlife Works

Wildlife Works Carbon LLC, one of the world's leading REDD project development companies, was originally established to help local landowners in the developing world to monetize their forest and biodiversity assets, whether they are governments, communities, ownership groups or private individuals.

Wildlife Works pioneered a novel business model that uses the marketplace to bring innovative economic solutions to wildlife conservation, reduce human/wildlife conflict and protect forests in the developing world.

The company's first project at Rukinga, Kenya has been operating for over a decade protecting wildlife and forests. This history has enabled Wildlife Works to launch the Kasigau Corridor REDD project, through which the company has expanded the area under protection to over 500,000 acres. Wildlife Works continues to bring the benefits of direct carbon financing to Kenyan communities, while simultaneously securing a contiguous wildlife migration corridor between Tsavo East and West National Parks.

Building on this successful model, Wildlife Works plans to leverage its experience in Southeastern Kenya to future REDD projects around the globe, with a goal to protect 5 million hectares from deforestation. Wildlife Works is committed to protecting wildlife, forests and biodiversity, with a direct, hands-on approach to creating alternative livelihoods.

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About ecoPartners

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1 Sources

This methodology was developed to the requirements set in:

- Voluntary Carbon Standard 2007.1

And with guidance of the following VCS approved Tools:

- Tool for AFOLU Methodological Issues
- Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination
- VT0001 Tool for the Demonstration and Assessment of Additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities

The authors of this methodology would also like to acknowledge and credit these previous publications that where considered in the drafting of this document.

- "Sourcebook for Land use, Land-Use Change and Forestry Projects," a publication by Winrock International and the BioCarbon Fund
- "Good Practice Guidance for Land Use, Land-Use Change and Forestry" reports by the IPCC
- "Global Forest Resources Assessment" 2005, 2010 reports by the FAO

2 Summary

This methodology provides a means to quantify Net Emissions Reductions and/or Removals (NERs) from project activities that avoid mosaic deforestation of tropical forests where deforestation is not driven by commercial harvest. It is common in tropical forests for deforestation to be driven by subsistence agriculture. In these areas, long-term cultivation is usually not feasible because of climatic constraints and changes and land use conversion sometimes results in desertification.

Under this methodology, project proponents implement project activities in the project area and surrounding region that address the agents and drivers of deforestation. The specific agents and drivers of deforestation can be identified using expert knowledge or a participatory rural appraisal, which is a type of community survey. Identifying the agents and drivers of deforestation is essential to designing effective strategies to mitigate deforestation.

The results of the survey are also used to define a reference region that informs the baseline scenario. The baseline scenario is characterized by a deforestation model that is developed using observations made during a defined historic period. The deforestation model predicts the cumulative deforestation that would have occurred in the absence of the project to estimate baseline emissions. A separate model that incorporates both deforestation and degradation is used to estimate leakage. Degradation is conservatively ignored in estimating baseline emissions to simplify accounting.

Leakage is quantified using a leakage area which may or may not be the same as the reference area. Like the reference area, though, the leakage area is defined by the agents and drivers of deforestation. However unlike the reference area, the leakage area is additionally defined by proximity to the project area and anticipated directional shifts in activities. The leakage area is more purposeful than a belt or an arbitrary buffer around the project area.

Compared to approaches taken by other REDD methodologies, the baseline deforestation model used in this methodology deviates significantly in two regards: First, the model predicts a cumulative proportion of deforestation over time rather than a rate of deforestation in hectares per year. Second, the model is fit using simple point observations of deforestation over a historic reference period rather than requiring a series of complex Land Use Land Cover (LULC) classifications of full-coverage satellite imagery.

These two approaches make the deforestation model particularly attractive to project developers for several reasons. First, the time required to build the model is relatively short. Almost any type of historical imagery can be used to build the model, including grey-scale aerial, color aerial, panchromatic, satellite, SAR or even Landsat 7 SLC-OFF imagery (despite its failed sensor). Second, despite the fact that cloud contamination may result in limited coverage of the reference region, all collected imagery can be used to build the deforestation model, in lieu of cloud cover within individual images. Once the imagery is imported into a geographic information system (GIS), data collection for model fitting is performed using simple, heads-up interpretation of point samples from the imagery. Thus, and most importantly, thematic land cover classifications of complete sets of images for each date in the reference period are not necessarily required.

In addition to the relative simplicity and robustness of the deforestation model, this methodology differentiates between carbon pools, and thus project developers will find this methodology particularly attractive. For example, both standing dead wood and lying dead wood are components of the dead wood pool but standing dead wood is measured using a plot while lying dead wood a line transect; since the dead wood pool is optional, the project developer may choose to conservatively omit lying dead wood. This avoids the added complexity of sampling line transects while still including the optional standing dead wood pool. Such an approach may be preferable to project developers as measurements of standing dead wood can easily be made at the same time as measurements of above-ground live trees on the same plot.

In general, this methodology monitors carbon stocks using a sample of fixed area plots in the project area. Lying dead wood is estimated using a line intersect sample, and soil carbon is estimated using samples removed from soil cores or pits located within the plots used for biomass estimation. This methodology also differentiates between above-ground large tree and small tree biomass. This is considered logical because large trees might be used differently than small trees under the baseline scenario and, in order to efficiently allocate sampling resources to the most substantial carbon pools, the sampling intensity for large trees might be greater than that for small trees. For example, to minimize sampling costs, the plot size for small trees might be smaller than the plot size for large trees.

Because this methodology uniquely differentiates between carbon pools, each major accounting section is purposely organized by carbon pool to facilitate ease of use; the baseline scenario, baseline emissions and monitoring sections are subdivided by carbon pool. In this way, project proponents may first select their carbon pools and then easily trace the accounting sections to find the appropriate methods. This is a departure from other methodologies, which typically attempt to account for all pools simultaneously despite the fact that some pools might not be used in the project.

Lastly, project proponents will find that this methodology provides cohesive transitions between the concepts that guide accounting while also providing necessary and important details of the accounting procedures themselves. To unify the text and tone of the methodology, complex equations and variables have been omitted from the body and placed in separate appendices. Essential equations are placed both inline and in an appendix. Project proponents should use these appendices side-by-side with the body of the methodology during project development and reporting. Appendix A is a comprehensive list of equations, literature sources, assumptions and comments by equation number while Appendix B is a list of variables, variable descriptions and units. All equations cited in the body of the methodology are hyperlinked by equation number to Appendix A and all equations are hyperlinked by section number back to the sections where they are used.

2.1 Notation

The notation used in this methodology is intended to clearly communicate the variables and mathematical processes intended for quantifying carbon stocks and project greenhouse gas benefits. The notation adopted differs in some ways from that seen in other forest carbon methodologies. These deviations improve the clarity and readability of this document.

Equations

Equations in this methodology are numbered and bracketed (e.g. [49]). The equations themselves are located in Appendix A, referenced in the text by number. The intent is that Appendix A will be printed and used as a separate document in conjunction with the text of the methodology. Equations in Appendix A contain additional information including citations, literature sources and comments while the in-line equations do not. Several important equations are reiterated in the text to facilitate the explanation of mathematical and accounting concepts. These inline equations have consistent numbering with the equations in Appendix A.

In some instances, similar operations are performed on different variables in multiple places. For example, estimating above-ground carbon stocks in the large tree, small tree, and non tree biomass pool all involve summing plot level measurements, dividing by plot area, summing across plots in a stratum, and multiplying by stratum area. Rather than repeat nearly identical equations for each estimate, we provide a single, generic equation like [50] with a placeholder variable x or y. To estimate each pool, the relevant variable or equation can be substituted for x as indicated by the methodology.

Variables

Variables in this methodology and their units are enumerated in the list of variables in Appendix B. The intent is that Appendix B will be printed and used as a separate document in conjunction with the text of the methodology. The variables x and y (with and without subscripts) are sometimes used as placeholder variables — they may stand in for another variable or the results of an equation as indicated by the methodology text. The variables x and y are also used to indicate geographic coordinates in the development of the deforestation and soil carbon loss models, in the baseline scenario section (section 6). The meaning of these variables should be clear based on the context provided in the methodology text.

Summations

Summations use set notation. Sets of variables are indicated using script notation. For example, $\mathcal{S}$ represents the set of all strata in the project area, while $\mathcal{P}_k$ represents the set of all plots in stratum k. Set notation greatly reduces the number of variables used in the methodology as well as the complexity of summations.

Elements

Elements of a set are denoted using subscript notation. A sum over the elements of a set is indicated by the notation $\sum_{k \in \mathcal{S}} a_k$. This particular example sum indicates the sum of the area of all strata, where a_k indicates the area of stratum k. The number of elements in a set is indicated by functional notation $\#(\mathcal{S})$ where the pound sign stands for “count of”.

Standard Deviations and Variances

Estimated standard deviation is indicated by the $\hat{\sigma}$ symbol, with subscripts used to indicate the quantity for which the uncertainty is estimated. Variance is indicated by $\hat{\sigma}^2$.

Standard Errors

Estimated standard error is indicated by the $\hat{\sigma}_{SE}$ symbol, with additional subscripts used to indicate the quantity for which the uncertainty is estimated.

Monitoring Periods

Monitoring periods are notated using bracketed superscripts $[m]$. The first monitoring period is denoted by $[1]$, the second monitoring period $[2]$ and so forth. These superscripts should not be confused with references to equations numbers, as equation numbers are never in superscript. Also see the definition for monitoring period in section 3.

Totals for Carbon Pools

Major carbon pools subject to project accounting are denoted by a capital C, with subscripts to differentiate between pools as indicated in the list of variables. For example, $C_{AGLT}^{[m]}$ indicates the carbon stock in above-ground large trees in monitoring period $[m]$. Subscripts from carbon pools are acronyms listed in section 3.1.

Quantified Uncertainties

Uncertainties in major carbon pools, expressed as proportions, are denoted using a capital letter U. For example, $U_{TOTAL}^{[m]}$ is used to indicate the uncertainty in total carbon stocks at monitoring period $[m]$.

Vectors

Vectors are indicated using bold face; for example $\boldsymbol{\theta}$ is the vector of covariate parameters to the cumulative deforestation model. This vector may include numerous elements such as the numeric effects of population density, road density or per-capita household income on predicted deforestation.

Matrices

Matrices are intentionally not used in this methodology to avoid complexity and confusion.

3 Definitions

Above-ground Biomass: Please see current VCS definition.

Additionality: GHG benefits that would not have occurred without the presence of the project.

Agent of Deforestation: People or groups of people responsible for deforestation.

Agriculture, Forestry and Other Land Use (AFOLU): Please see current VCS definition.

Allometric Equation: A statistical model used to predict biomass given the measurement of closely related attributes of a tree or shrub, such as diameter (DBH) or stem count.

Baseline Scenario: The “without-project scenario” that would have occurred had the project not been implemented. The baseline scenario is counterfactual. The baseline scenario is characterized by a deforestation model that is developed using observations made during a defined historic period. The deforestation model predicts the cumulative deforestation that would have occurred in the absence of the project.

Baseline Emissions: For any monitoring period, baseline emissions $C_{BE}^{[m]}$are a sum of estimated emissions over selected carbon pools.

Baseline Reevaluation: Revision of the baseline scenario which occurs at least every ten years, see section 6.7.

Below-ground Biomass: Please see current VCS definition.

Carbon Fraction: The proportion of biomass that is carbon, which may vary by species. The IPCC default is 50% (IPCC, 2003).

Carbon Pools: A reservoir of carbon (sink) that has the potential to accumulate (or lose) carbon over time, which for AFOLU projects typically encompass above-ground biomass, below-ground biomass, litter, dead wood and soil.

Carbon Stock: Please see current VCS definition.

Covariate: A variable possibly predictive of the outcome under study; in this case quantifiable social, economic, or political factors that may improve model fit.

Dead Wood: Please see current VCS definition.

Deforestation: Please see current VCS definition.

Degradation: Please see current VCS definition.

Drivers of Deforestation: Geographic, climatic or other physical, social and/or economic conditions that cause deforestation.

Emissions: The release of a greenhouse gas (GHG) source into the atmosphere.

Foreign Agents: Groups originating outside the region in which the project resides (for example, a group of settlers that emigrates a far distance inland from the coast).

Forest: Please see current VCS definition.

Grassland: Please see current VCS definition.

Grouped Project: Please see current VCS definition.

Large Tree: A tree with diameter greater than the designated size class diameter.

Leakage: Please see current VCS definition.

Litter: Please see current VCS definition.

Long-Lived Wood Products: Products derived from wood harvested from a forest, including logs and the products derived from them, such as sawn timber and plywood that are assumed to remain sequestered throughout the lifetime of the project crediting period.

Methodology: A specific set of criteria and procedures which apply to specific project activities for identifying the project boundary, determining the baseline scenario, demonstrating additionality, quantifying net GHG emission reductions and/or removals, and specifying project monitoring procedures.

Monitoring Period: An interval of time following the project start date and project crediting period start date designated for systematically verifying project claims of GHG emissions reductions and/or removals and project additionality. Specifically, an interval of time from $t_1^{[m]}$ to $t_2^{[m]}$ where $t_1^{[m]} \geq 0$ (the project crediting period start date) and $t_1^{[m]} < t_2^{[m]}$. The length of the monitoring period is $t_2^{[m]} - t_1^{[m]}$ where m denotes the number of any single monitoring period. The length of each monitoring period must be less than or equal to five years.

Native Ecosystem: Please see current VCS definition.

Net GHG Emission Reductions and Removals (NERs): Tonnes of Carbon Dioxide Equivalent (CO_2-e) emissions that are reduced or removed from the atmosphere due to project activities during the project crediting period.

Non-tree Woody Biomass: Biomass that includes woody shrubs and any trees too small for carbon stock estimation using the allometric equations derived or selected for trees.

Participatory Rural Appraisal: A voluntary survey of the populace surrounding the project area that can be used to identify the agents and drivers of deforestation, delineate the reference region, and identify strategies to mitigate deforestation in the project area.

Peat Soil: Organic material with more than 50% of organic matter derived from incompletely decomposed plant residues.

Permanent Plot: A plot with fixed area and location used to repeatedly measure carbon stocks over time.

Project Activity: The specific set of technologies, measures and/or outcomes, specified in a methodology applied to the project, that alter the conditions identified in the baseline scenario and which result in GHG emission reductions or removals (please see current VCS definition). Conditions may be social or economic, not necessarily the condition of deforestation.

Project Boundary: The physical and temporal constraints of the project that encompasses the greenhouse gases (GHG) and carbon pools considered which include the physical boundaries of the project area and the project crediting period defined by the project proponent.

Project Crediting Period: Please see current VCS definition. The length of this period must be equal-to or less-than the period defined by the temporal project boundaries.

Project Crediting Period Start Date: Please see current VCS definition.

Project Description: Please see current VCS definition.

Project Developer: The project proponent or an entity working on behalf of the project proponent that is responsible for designing and/or implementing the project.

Project End Date: The date of the end of the last monitoring period and the conclusion of the Project Crediting Period.

Project Emissions: Project emissions for any monitoring period $[m]$as estimated by the events of woody biomass consumption.

Project Proponent: Please see current VCS definition.

Project Start Date: Please see current VCS definition. This date might come before or on the project crediting period start date.

Reduced Emissions from Deforestation and Degradation (REDD): Please see current VCS definition.

Reference Area: An area in the same region as the project area that is similar to the project area in regards to acting agents of deforestation, acting drivers of deforestation, socio-economic conditions, cultural conditions and landscape configuration.

Reference Period: A historic period of time in the same region as the project that is similar in acting agents of deforestation, acting drivers of deforestation, socio-economic conditions, cultural conditions and landscape configuration to the project area.

Reference Region: The reference area (space) and period (time).

Residual Biomass Coefficient: The portion of below-ground tree biomass lost as a result of land use conversion to annual crops by deforestation.

Size Class Diameter. The diameter at breast height (DBH) that distinguishes small trees from large trees, below which the below-ground tree biomass is completely removed and above which the below-ground tree biomass is partially removed as a result of land use conversion to agriculture.

Small Tree: A tree with diameter less than the size class diameter.

Soil Organic Carbon: Please see current VCS definition.

Stratification: The process of grouping homogenous subgroups of a given population to reduce sampling measurement error.

Temporal Project Boundary: This is the period of time when deforestation is mitigated in the project area as a result of project activities. The boundaries are defined by the project start and end date.

Uncertainty: Please see current VCS definition.

Validation/Verification Body (VVB): Please see current VCS definition.

Verification Period: Please see current VCS definition.

Woody Biomass: Biomass resulting from secondary growth.

Wood Products: Please see current VCS definition.

3.1 Acronyms

AGLT	Above-ground Large Tree
AGST	Above-ground Small Tree
AGNT	Above-ground Non-Tree
AFOLU	Agriculture, Forestry and Other Land Use
AUMDD	Avoided Unplanned Mosaic Deforestation and Degradation
BE	Baseline emissions
BGLT	Below-ground Large Tree
BGST	Below-ground Small Tree
BGNT	Below-ground Non-Tree
BR	Baseline Reevaluation
CDM	Clean Development Mechanism
CF	Carbon fraction
DBH	Diameter at breast height
DF	Deforestation
FAO	Food and Agriculture Organization
FD	Forest degradation
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LDW	Lying dead wood
LE	Emissions from leakage
MC	Moisture content
NERs	Net GHG Emission Reductions and/or Removals
PD	Project Description
PE	Project emissions
REDD	Reduced Emissions from Deforestation and Degradation
SCL	Soil carbon loss

SDW	Standing dead wood
SE	Standard error
SOIL	Soil
U	Uncertainty
UNFCCC	United Nations Framework Convention on Climate Change
VVB	Validation/Verification Body
VCS	Voluntary Carbon Standard
VCSA	Voluntary Carbon Standard Association
VCU	Voluntary Carbon Unit
WP	Long-lived wood products

4 Applicability Conditions

For this methodology to be applied, project activities must satisfy the following conditions:

1. This methodology was developed for avoiding deforestation and assumes that degradation and deforestation occur as a result of land use conversion to agriculture for the cultivation of non-perennial (annual) crops rather than for commercial timber harvest. This methodology may be used if all the drivers and agents of deforestation are consistent with those described in section 6 of this methodology.

2. Once forest is converted to agriculture in the reference and leakage areas, that conversion is permanent and the land is not allowed to return to forest. This excludes use of this methodology for Swidden or other traditional forest cultivation activities that clear one area to farm for a year or two, and then move on and leave that area to return to forest over decades. It does not exclude converted areas where selective fields within a farm or agricultural area are abandoned due to soil depletion or are left fallow to recover but are continuously under agricultural or other anthropogenic use, and will not return to forest.

3. Forest land in the project area has qualified as forest as defined by FAO 2010 or that of the definition of forest set by the residing designated national authority (DNA) for the project country for a minimum of 10 years prior to the project start date (VCS, 2008).

4. No biomass is harvested for use in long-lived wood products in the project area under the with-project scenario. Therefore, carbon sequestered in long-lived wood products under the project during any monitoring period $[m]$ may be accounted for as zero.

5. If the soil carbon pool is selected and the default mean rate of soil carbon loss is selected, then the project must be located in a tropical or semi-arid tropical region.

6. Foreign agents of deforestation, if any, are unlikely to shift their activities outside the leakage area.

7. The project area shall not contain organic or peat soils.

8. A reference area can be delineated meeting the requirements described in section 6.3.1 of this methodology including the minimum size requirement.

9. As of the project start date, historic imagery of the reference region exists with sufficient coverage to meet the requirements of section 6.4.2 of this methodology.

10. Project activities are planned or implemented to mitigate deforestation by addressing the agents and drivers of deforestation as described in section 10.1 of this methodology.

11. The project proponents have access to the leakage area to sample forest degradation (see section 10.3.2).

12. If the lag period for the cumulative leakage model is estimated after the project start date but before the end of the first monitoring period (see section 10.3.3), then activity-shifting leakage has not occurred prior to the estimation of the lag period.

13. Project areas shall not include land designated for legally sanctioned logging activities.

PD Requirements: Applicability Conditions

The project description must include the following:

1. Credible evidence that all applicability conditions have been met.

5 Project Boundaries

The physical and temporal constraints of the project as well as the greenhouse gases and carbon pools must be clearly delineated and defined by the project proponent. Bounds must conform to the latest guidance from the VCS and this methodology, and must be clearly and objectively defined to facilitate monitoring and evaluation.

5.1 Delineating the Spatial Boundaries

At a minimum, project lands must meet the definition of forest given in the definitions in section 3. The project area may consist of multiple contiguous or discontinuous forested parcels.

The geographic or physical bounds of the project must be clearly delineated using, at minimum, the following:

- Name of the project area (compartment or allotment number, local name)
- Digital maps of the area, including geographic coordinates of vertices
- Total land area
- Details of ownership, including user rights and/or land tenure information
- Topography
- Roads
- Major rivers and perennial streams
- Land use/vegetation type classification

The project area must be under the control of the project participants defined in the PD at project verification. If validation occurs before verification, and less than 80% of the project area is under control at the time of validation, project participants must demonstrate:

- The difference in land area does not affect additionality.
- In the event the project proponents are not able to eventually control all assumed project areas, provisions are in place to assure that emissions from these areas shall be considered as leakage.
- The monitoring plan is sufficiently flexible to account for changes in the project size.

In all cases, the project must be verified within the time allotted under current VCS rules (VCS, 2008).

The size of the project area cannot increase after the end of the first monitoring period.

PD Requirements: Spatial Project Boundaries

The project description must include the following:

1. A digital (GIS) map of the project area with at least the above minimum requirements for delineation of the geographic boundaries.

2. Credible documentation demonstrating control of the project area, or documentation that the provisos listed in the case of less than 80% project control at the time of validation delineated in this methodology are met.

5.2 Defining the Temporal Boundaries

Temporal boundaries define the period of time when deforestation in the project area is mitigated by project activities. Lands must have qualified as “forest” for a minimum period of time prior to the project start date, as specified by the VCS standard. The temporal boundaries include the project crediting period which is fixed by the project proponent.

Projects may use an historical crediting period under specific circumstances. The VCS standard should be referenced to ensure that the project temporal boundaries are developed to be consistent with current VCS regulations. Currently, a project start date and project crediting period start date can may be historic back to January 1, 2002, provided that the project proponent can demonstrate that GHG Emission reduction activities consistent with the REDD project design, such as forest protection, community leakage mitigation and other REDD project activities, were being undertaken by project proponent as of the project start date. The project proponent may not receive credit for carbon sequestration between the project crediting period start date and the first verification, but provided that the GHG Monitoring for the first verification is performed using an approved VCS REDD methodology, then credit for emissions reductions based on the carbon inventory at the time of first verification may be claimed back to the project crediting period start date.

The following temporal boundaries shall be defined:

- The start date of the project.
- The start date of the project crediting period.
- The length if the project crediting period.
- The dates and periodicity of baseline revision and monitoring periods. Baseline reevaluation after the project start date and monitoring must conform to the current VCS standard.

The project crediting period start date may occur after the project start date. If the project crediting period start date is more than ten years after the project start date, then as of the project crediting period start date a baseline reevaluation must occur prior to the first monitoring period (see section 6.7).

PD Requirements: Temporal Project Boundaries

The project description must include the following:

1. The project start date.
2. The project crediting period start date and length.
3. The dates for mandatory baseline reevaluation after the project start date.
4. Credible documentation that lands claimed as forest qualified were such for a minimum time period prior to the project start date, as specified by the current VCS standard.

The project description may also include:

5. A timeline including the first anticipated monitoring period showing when project activities will be implemented.
6. A timeline for anticipated subsequent monitoring periods.

5.3 Gases

Project proponents must account for significant sources of the following included greenhouse gases:

Gas	Sources	Inclusion	Justification
CO_2 (Carbon Dioxide)	Flux in carbon pools	Yes	Major pool considered in the project scenario
CH_4 (Methane)	Burning of biomass	No	Conservatively excluded
N_2O (Nitrous Oxide)	Burning of biomass	No	Conservatively excluded

5.4 Selecting Carbon Pools

Project proponents must account for the required pools (below) and may additionally select from the listed optional pools:

Pool	Required	Justification
Above-ground large tree biomass	Yes	Major pool considered
Above-ground small tree biomass	Yes	Major pool considered
Above-ground non-tree biomass	Optional	May be conservatively excluded
Below-ground large tree biomass	Optional	May be conservatively excluded
Below-ground small tree biomass	Optional	May be conservatively excluded
Below-ground non-tree biomass	Optional	May be conservatively excluded
Litter	No	Conservatively excluded
Standing dead wood	Optional	May be conservatively excluded
Lying dead wood	Optional	May be conservatively excluded
Soil	Optional	May be conservatively excluded
Long-lived wood products	Yes	May be a significant reservoir under the baseline scenario

Optional pools may be conservatively excluded if the sum of all emission from optional pools not selected is less than 5% of the total project benefit for the project lifetime (VCS, 2010a). The conservative exclusion of *de minimus* pools can be demonstrated using *ex-ante* estimates (see section 11.3). Conservative exclusions must always meet current VCS requirements.

Large trees are differentiated from small trees by a specific DBH. The important distinction between these classes of trees is that, under the baseline scenario, below-ground biomass of small trees is assumed to be completely removed, while below-ground biomass of large trees may remain in part on site. This diameter is called the size class diameter and must be selected by the project proponent based on the following criteria:

- Empirical evidence based on past land use conversion events to agriculture, considering the mechanisms used for land clearing and observed residual biomass remaining in the soil after the conversion.
- The tree diameter below which the belowground tree biomass is completely removed as a result of land use conversion to agriculture.
- The tree diameter above which the belowground tree biomass is partially removed as a result of land use conversion to agriculture.

If there is no clear distinction between small trees and large trees with respect to these criteria, then any size class diameter can be used. In this case, a project proponent may select a size class diameter that minimizes sampling costs, as small trees can be measured using different sized plots than large trees (see section 13.5). The selection of a relatively small diameter is considered conservative.

Required and optionally selected carbon pools are hereby referred to as a set denoted by $\mathcal{C}$ (see section 2.1).

PD Requirements: Carbon Pools

The project description must include the following:

1. A list of the greenhouse gases considered.
2. A list of the carbon pools selected.
3. The selected size class diameter.
4. Rationale and evidence to support the selected size class diameter, if applicable.

5.5 Grouped Projects

Grouped projects are allowed, where each instance is treated as a discrete part of a single project area. All instances that are grouped must be in the same region and must each meet all the applicability conditions of this methodology, including applicability conditions related to the baseline scenario (see sections 4 and 6). One project description should be generated for all instances but must reference the individual instances in the group where appropriate. All instances must be exactly the same with regard to a common reference region, baseline scenario and leakage (see reporting requirements in sections 6, 6.3 and 10). Project documentation may vary with respect to carbon stock estimation as stratification and plot location will vary by instance (see reporting requirements in section 13.14) and project emissions (see reporting requirements in section 9). Project proponents should always refer to the full rules and requirements for grouped projects in the most recent version of the VCS Standard.

PD Requirements: Grouped Projects

If grouped projects are developed, then the project description must include the following:

1. A list and descriptions of all instances in the group.
2. A map of the locations or boundaries of all instances in the group indicating that all instances are in the same region.
3. A map of the common reference area.

6 Baseline Scenario

6.1 Overview

The baseline scenario is defined by two models that predict what would have happened in the project area had the project not been initiated (the “without-project” scenario). They are:

- The cumulative deforestation model, which predicts percent deforestation in the future, using past observations.
- The soil carbon loss model, which predicts the decay of carbon in soil under the baseline scenario.

It is likely that the most important of these models for any project will be the cumulative deforestation model, as it accounts for the greatest portion of baseline emissions.

The cumulative deforestation model is a function of time and some external, quantifiable drivers of deforestation such as population density, length of road in the region or median household income. These external, quantifiable drivers of deforestation are called covariates due to their correlation with deforestation in the region. The model is primarily constructed using observations made from a reference region which either surrounds or is near to the project area. The boundaries and size of the reference region are subjective and are optionally defined by the results from a participatory rural appraisal.

The participatory rural appraisal is a survey that can be conducted by the project proponent in the region surrounding the project area prior to fitting any baseline models or delineating the reference region. Once the participatory rural appraisal is completed and the results are analyzed, the project proponent may define the reference region and subsequently fit the deforestation model.

The participatory rural appraisal is an optional tool that suffices to identify the agents and drivers of deforestation in the event that the agents and drivers are not obvious. If, during validation, the agents and drivers of deforestation are found not to be evident, a participatory rural appraisal must be conducted. If a participatory rural appraisal is not used, then statistics about the agents and drivers obtained from published or unpublished sources should be used to demonstrate their prevalence.

It is conservative to ignore degradation under the “without-project” scenario and therefore this methodology only provides baseline scenarios for deforestation.

PD Requirements: Obvious Agents and Drivers of Deforestation

If a participatory rural appraisal is not used, the project description must include the following:

1. A list of the evident agents and drivers of deforestation, including quantitative descriptions of agent mobilities.
2. A narrative describing why the agents and drivers of deforestation are evident.
3. Descriptions of agents and drivers including any useful statistics and their sources.
4. A list of project activities designed to mitigate deforestation listed in order of importance.
5. A list of external drivers (covariates) of deforestation used in the model, if any (e.g. median household income, road density, rainfall).

6.2 The Participatory Rural Appraisal

The participatory rural appraisal is a voluntary survey of the populace surrounding the project area and may be used to identify the agents and drivers of deforestation, delineate the reference region and identify strategies to mitigate deforestation in the project area.

The participatory rural appraisal utilizes a questionnaire to identify the agents and drivers of deforestation. The survey should sample as many community members, community leaders, customary leaders and public officials as possible given time and expense constraints. The sample size selected by the project proponent affects the creditability of the agents and drivers identified using the appraisal and a very low sample size may negatively affect the validation opinion. The questionnaire should be anonymous and may contain both closed and open-ended questions. The questionnaire can be issued in written form or administered orally to individuals or groups of people, as is deemed appropriate by local culture and custom. Incentives should be considered to increase the number of responses, taking care not to bias results with said incentives. The questions are designed by the project proponents on an individual project basis and should address the following issues:

1. Possible agents of deforestation, including:
   a. Foreign groups;
   b. Local groups;
   c. Regional groups;
   d. Customary and traditional groups;
   e. Community groups;
   f. Authorities and governments;
   g. Illegal activities; and
   h. Other possible agents.
2. Possible drivers of deforestation, including:
   a. Historic problems with community sustainability;
   b. Livelihoods;
   c. Economies;
   d. Rural wages;

   e. General scarcity issues;
   f. Prices of agricultural products;
   g. Costs of agricultural inputs;
   h. Human-wildlife interaction;
   i. Illegal or black markets;
   j. Historical and current forest uses;
   k. Population density;
   l. Socio-economic conditions; and
   m. Property-ownership systems;
   n. Other possible drivers.

3. Possible time components of deforestation, including;

   a. Arrival of foreigners;
   b. Changes in transportation infrastructure;
   c. Events of significant importance such as droughts or floods;
   d. Regional climatic trends;
   e. Events of significant population growth;
   f. Events of significant economic growth or decline;
   g. Expected community needs;
   h. War or other conflicts;
   i. Changes in policies; and
   j. Other possible time components.

4. Possible constraints to deforestation, including:

   a. Access issues;
   b. Soil productivity;
   c. Topography;
   d. Proximity to markets;
   e. Proximity to other resources (water, electricity, transportation);
   f. Protected areas;
   g. Ownership types (government, private, reserve) ; and
   h. Other possible constraints.

5. Relative importance of drivers and agents of deforestation in respondents' estimation (a relative numerical rank).

6. Possible solutions to community un-sustainability.

PD Requirements: Participatory Rural Appraisal

If a participatory rural appraisal is used then the project description must include the following:

1. A copy of the questionnaire and an archive of all responses that can be easily produced for validation/verification purposes.
2. The sample size of the survey.
3. The locations where the survey was administered.
4. The date(s) when the survey was administered.
5. The number of responses.

6.2.1 Analyzing the Agents of Deforestation

Analyze responses from the survey with respect to the agents of deforestation by first enumerating the responses to agent-based questions. Then, group these responses by the agents identified in the responses. Next, rank groups by the number of responses that fall within any particular group. One response may fall into more than one group. Consider responders' ranking of relative importance when ranking groups. Sort the list of groups by decreasing rank and for each agent of deforestation in the list, describe its mobility. Also provide a description of the agent relative to possible drivers of deforestation and any useful statistics about the agent obtained from published or unpublished sources.

The sorted list of agents forms the basis for developing project activities that mitigate deforestation in order of importance. Elements of the list may identify possible covariates which could be included as numeric drivers of deforestation in the cumulative deforestation model. These covariates must be quantifiable, such as population density data from periodic census or head of cattle in a local community.

PD Requirements: Analysis of Agents of Deforestation

If a participatory rural appraisal is used then the project description must include the following:

1. A list of agents by rank and number of responses.
2. Descriptions of agents including any useful statistics and their sources.
3. A list of agents including descriptions of agent mobilities.
4. A list of project activities designed to mitigate deforestation in order of importance.
5. A list of possible external numeric drivers (covariates) of deforestation, if any.

6.2.2 Analyzing the Drivers of Deforestation

Analyze responses from the survey with respect to the drivers of deforestation by first enumerating the responses to driver-based questions. Then, group these responses by the drivers identified in the responses. Rank these groups by the numbers of responses that fall within in any particular group. One response may fall into more than one group. Consider responders' ranking of relative importance when ranking groups. Sort the list of groups by decreasing rank. Also provide any useful statistics about the driver obtained from published or unpublished sources.

The sorted list of drivers forms the basis for developing project activities that mitigate deforestation in order of importance. Elements of the list may identify possible covariates which could be included as numeric drivers of deforestation in the cumulative deforestation model.

PD Requirements: Analysis of Drivers of Deforestation

If a participatory rural appraisal is used then the project description must include the following:

1. A list of drivers of deforestation by rank and number of responses.
2. Useful statistics about the drivers and their sources.
3. A list of project activities designed to mitigate deforestation in order of importance.
4. A list of possible external numeric drivers (covariates) of deforestation, if any.

6.3 The Reference Region

The reference region is used to build the cumulative deforestation model under the baseline scenario (the "without-project scenario"). It is defined in both space and time; the space component of the reference region is called the reference area while the time component of the reference region is called the historic reference period. The reference area is used to determine the landscape pattern of mosaic deforestation while the reference period is used to determine the change in the cumulative proportion of deforestation over time.

The reference region is exclusively defined by the agents and drivers of deforestation (VCS, 2008b). The agents and drivers of deforestation can be identified by the participatory rural appraisal or expert knowledge in the case that the agents and drivers are clearly evident. The delineation of the reference region is intentionally a subjective exercise, as the agents and drivers of deforestation differ by project location, and sometimes even within the same region.

This methodology deliberately omits a quantitative determination of the size of the reference area. It is considered unlikely that such a formula would include variables for the agents and drivers of deforestation, as these are difficult metrics to quantify. Likewise, this methodology does not specify a fixed historic reference period length. Instead, the reference period is defined simply by the availability of historic images for the reference area and important past events related to deforestation as identified from the participatory rural appraisal.

6.3.1 Delineating the Reference Area

The reference area is delineated using the relevant drivers and agents of deforestation as identified by expert knowledge or the participatory rural appraisal. The reference area must be in the same general region as the project area, but not necessarily adjacent to the project area. The size of the reference area must be at least the size of the project area but does not need to be contiguous with the project area. The reference area may not include the project area and may not be altered during the historic reference period. The boundaries of the reference area may include one or more of the following:

- Environmental, natural or political boundaries.
- Major transportation infrastructure such as highways or railroads.
- Land ownership/tenure boundaries.
- Latitudinal or Longitudinal degree boundaries.

The boundaries and size of the reference area must address the following criteria in order to ensure that the agents and drivers of deforestation in the reference area are similar to those of the project area:

1. The locations of the agents of deforestation relevant to the project area.

2. The nobilities of the agents of deforestation relevant to the project area.

3. The drivers of deforestation including the following relevant to the project area:

    a. Socio-economic conditions; and
    b. Cultural conditions.

4. Landscape configuration including the following relevant to the project area:

    a. Topographic constraints to deforestation (slope, aspect, elevation);
    b. Land use and/or land cover constraints to deforestation;
    c. Access points that may constrain deforestation;
    d. Areas of limited soil productivity;
    e. Proximity to important markets;
    f. Proximity to important resources (water, electricity, transportation); and
    g. Ownership/tenure boundaries that constrain deforestation (government holdings, private holdings and reserves).

The interpretation of these criteria is subjective and the project developer should always choose boundaries that result in the most conservative baseline scenario. The following analyses may be helpful to identify the boundaries and size of the reference region:

- Mapping the locations of agents of deforestation.
- Buffering the locations of agents based on the distance of their mobility.
- Provincial, district-level or local maps showing the relative socioeconomic conditions of local communities.
- Mapping the locations of important cultural places.
- Digital elevation models.
- Maps of topographic surveys.
- Maps of land use and land cover.
- Mapping the locations of access points that may constrain deforestation.
- Maps of soil productivity.

- Buffering the locations of important markets according to agent mobility.
- Maps of important resources (water, electricity, transportation).
- Maps of ownership boundaries (government holdings, private holdings and reserves).

The project area and reference area will be similar by virtue that they are located in the same region and are probably subject to the same agents and drivers of deforestation. However for substantiation, the project proponent should clearly demonstrate similarity using the following criteria:

1. The reference area and project area must be located with the same proximity to the agents of deforestation (for instance if the agents reside in a town, the project area and reference area must be similar in distance from a town in which agents of deforestation reside. These may be the same agents, or they may be different, but similar agents.)

2. Agents of deforestation must have access (legal or otherwise) to both the reference area and project area. The same agents need not have access to both areas, but the agents with access to each area must be similar in regards to the drivers of deforestation identified in section 6.2.2.

3. The reference area and project area have similar:

   a. Socio-economic conditions; and
   b. Cultural conditions.

4. The reference area and project area must have similar landscape configuration (for instance, the same topography and land cover).

5. The reference area must have at least the same area of forest cover as the project area at any point in the reference period. This can be demonstrated by a thematic classification of land cover in the reference area at some point in the reference period and the project area, or by some other credible method.

PD Requirements: Delineation of the Reference Area

The project description must include the following information with respect to the reference area:

1. A map of the delineated boundaries.
2. Maps of the landscape configuration, including:
    a. Topography (elevation, slope, aspect);
    b. Recent land use and land cover (either a thematic map created by the project proponent or publically available map);
    c. Access points;
    d. Soil class maps (if available);
    e. Locations of important markets;
    f. Locations of important resources like waterways or roads; and
    g. Land ownership/tenure boundaries.
3. A narrative describing the rationale for selection of reference region boundaries.
4. Demonstration that the reference area has at least the same area of forest cover as the project area.

6.3.2 Defining the Reference Period

The reference period must be established by important historic events as identified by the information obtained from expert knowledge or the participatory rural appraisal and corresponding analysis of agents and drivers of deforestation. These events include the following:

- The arrival time of specific foreign agents of deforestation, if any;
- The times when the drivers of deforestation became apparent, if any; and
- The times of significant economic growth or decline.

Historic imagery of the reference area should be acquired for times before and after these events and this imagery should be used to construct the cumulative deforestation model per section 6.4. If no important events are identified, then the reference period should be established by the times of available historic images of the reference area.

PD Requirements: Defining the Reference Period

The project description must include the following with respect to the reference period:

1. Established reference period boundaries.
2. A list of available historic imagery for the reference area.
3. A timeline of important events as they relate to the agents and drivers of deforestation.
4. Narrative rationale for the selection of the reference period.

6.4 The Cumulative Deforestation Model

The baseline scenario is estimated using a model of the cumulative deforestation that likely would occur in the project area given observed deforestation in the reference region. The model is parameterized from observations of forest state change in the reference area over the reference period. The parameterized model predicts the future degree of deforestation at any point in time after the project start date, expressed as a proportion.

The cumulative deforestation model is applicable to all carbon pools under the baseline scenario.

6.4.1 Background

This background section contains general information about the model and the selected approach to fitting the model rather than specific methods used to build the cumulative deforestation model, and is not required to run the model itself.

Deforestation over time is inherently bounded by the size of the area that is subject to deforestation and has been shown to exhibit logistic behavior over time (Arellano-Neri & Frohn, 2001; Kaimowitz, Mendez, Puntodewo, & Vanclay, 2002; Linkie, Smith, & Leader-Williams, 2004; Ludeke, Maggio, & Reid, 1990; Mahapatra & Kant, 2005). Figure 1 illustrates this behavior: the deforestation rate is low at beginning, steadily increases and tapers off at the end of the time period.

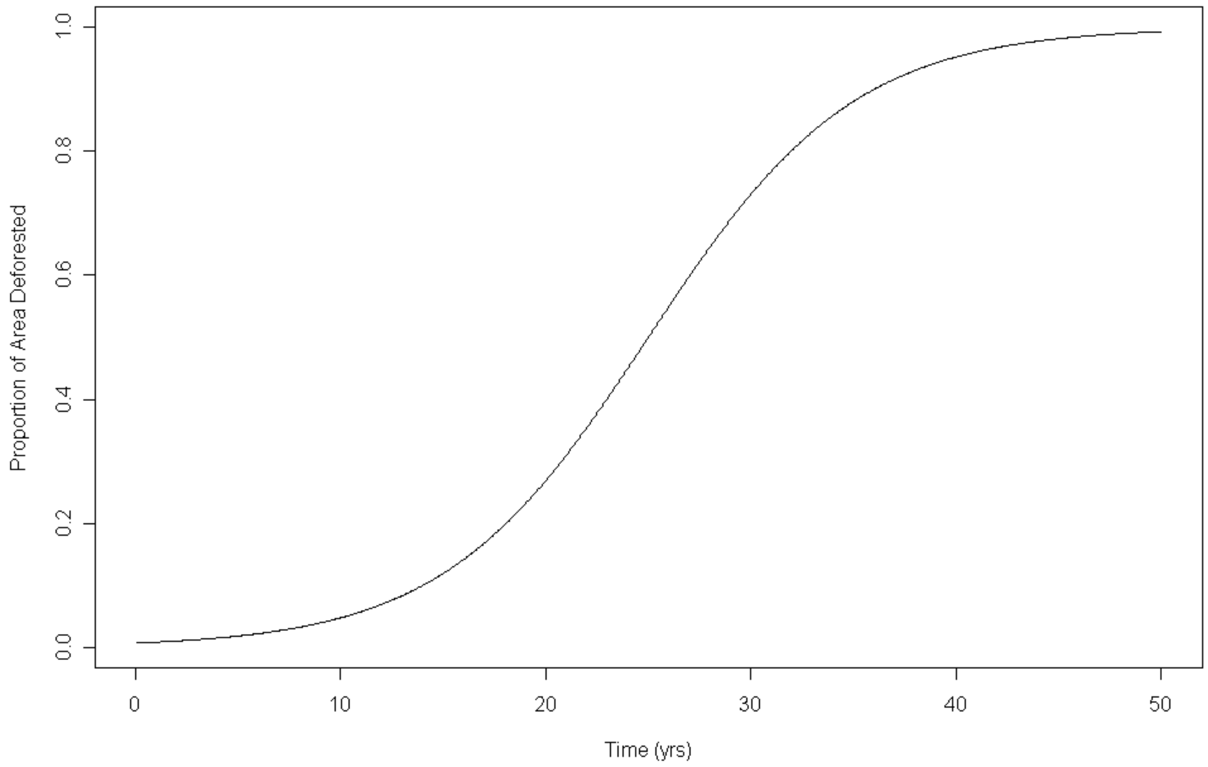

Figure 1: Graph of a logistic function.
The logistic behavior of deforestation over time.

This behavior can be interpreted using economic theory (Reis and Guzman 1992). At the beginning of deforestation in an area, agents are scarce and resources are plentiful; this leads to increasing resource exploitation. Conversely, toward the end, agents are plentiful and resources are scarce, decreasing exploitation.

Based on rational intuition and support from the literature, this methodology assumes that deforestation is logistic when bounded by the reference area or project area. Specifically, it assumes that deforestation over time exhibits the implicit form defined by equation [16].

$$F_{DF}(t,\eta) = \frac{1}{1+\exp[-\eta(t,\boldsymbol{\theta})]} \qquad [16]$$

The parameter vector $\boldsymbol{\theta}$ included in equation [16] represents the aforementioned numeric covariates to deforestation which are identified using expert knowledge or the participatory rural appraisal. The function η is called the linear predictor given time and deforestation covariate parameters $\boldsymbol{\theta}$. Fitting equation [16] is equivalent to estimating the linear predictor as $\hat{\eta}$ where the linear predictor is defined by equation [7].

$$\eta = \alpha + \beta t + \boldsymbol{\theta}\boldsymbol{x}^T \qquad [7]$$

Fitting equation [16] requires some historic information about the forest state in the space of the reference area over time. Observations of forest state (also called “forestation”) in the reference area can be made over the reference period as a first step to fitting equation [16]. These observations can be made using a sample of unique points in time and space where the state observation for the i^{th} sample point is defined by [1] which is a function of time t_i, latitude x_i and longitude y_i. State observations in space can be made at random or on a lattice (systematic grid). Since states are observed in historic images, however, observations in time can only be made at the times for which imagery is available.

Spatial availability of historic imagery over the reference area might not be uniform. Additionally, the entire space of the reference region might not be equally observed over time. To correct for any resulting bias, we estimate the probability of observing any one particular sample point using equation [2]. The probability of observing an image in time is not independent of space. For example, consider a scenario in which a government entity obtained aerial imagery along a highway for a road expansion project in the reference area five years prior to the project start date. Then, a second set of imagery was obtained after the road expansion was complete. Equation [2] accounts for the fact that the probability of observing an image in the reference area at any given time is dependent on that image’s proximity to the construction project.

The conditional probability of observing a sample point in space given time is [3] and the probability of observing any sample point in time is simply the intensity of the process [4]. Hence the correction factor is proportional to the inverse of the probability of observing any one particular sample point which is [5], and is called the observation weight.

$$w_i \propto \frac{1}{\#(observations\ at\ x_i, y_i) \times \#(observations\ at\ t_i)} \qquad [5]$$

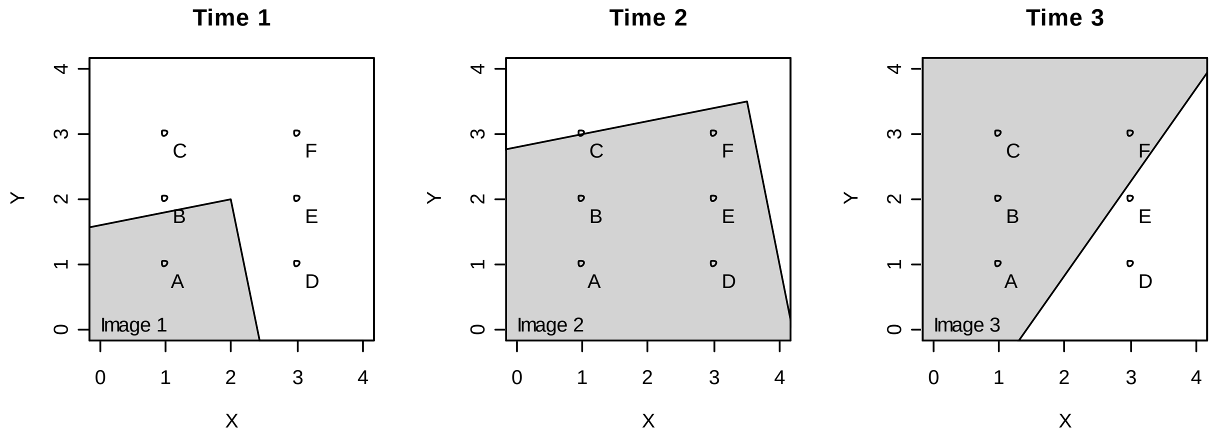

Figure 2: Examples for calculating observation weights.
An example of three images at different times used to calculate the observation weights of sample points.

For example, to calculate the observation weight of a point (x, y, t) as defined by equation [5], one must know the number of times the point was observed in the reference area and the number images that the point falls onto during the reference period where the point falls onto in the cloud-free portion of each image. If there are six points in the reference area and three images in the historic reference period, as shown in Figure 2, then the weight of point A at time 3 in the figure is calculated as

$$\frac{1}{3 \times 4} = \frac{1}{12}$$

while the weight of point D at time 2 is calculated as

$$\frac{1}{1 \times 5} = \frac{1}{5}.$$

Point D at time 2 is given more weight than point A at time 3 because it is observed less often.

The model defined by equation [16] is fit using iteratively reweighted least squares (IRLS) with initial weights $\boldsymbol{w}$, the observation weights, and given the observed covariates and states $\boldsymbol{o}$ in vector format. See Venables & Ripley (2002) for information on how to fit a logistic model with IRLS using the free statistical program R.

Akaike Information Criterion (AIC) is used to select the best nested model in $\boldsymbol{\theta}$. See Davidson (2003) or Freedman (2009) for information about linear predictors and logistic models.

The residuals of the model defined by equation [16] are assumed to be stationary over the reference period. That is, the mean and variance of the residuals are time invariant.

After model selection and fitting, the cumulative deforestation as a proportion of an area can be predicted for future times using equation [16].

6.4.2 Building the Cumulative Deforestation Model

Theoretical derivation aside, the cumulative deforestation model is a necessary tool to predict deforestation in the project area under the baseline scenario (the “without-project” scenario). The model is constructed in three sequential steps: First, deforestation in the reference area is observed in historical imagery over the reference period. Second, the model is fit using standard statistical software and finally, the uncertainty in the model is estimated.

This methodology maintains a fictitious example to illustrate these steps. This example assumes a reference area of 10 by 10km in dimension (100km^2) and a project start date of 1/2011.

Deforestation is sampled from available historical imagery of the reference area over the reference period. The project proponent must have at least “double coverage” for 90% of the reference area over the entire reference period.

This fulfillment of this requirement can be demonstrated by aligning a dot grid of points over the reference area using a GIS. Then, for each co-registered image in the system, those grid points that fall over the cloud-free, visible portion of each image are copied to a new file. This is done for all images and produces the same number of shape files as number of images. All derived shape files are then merged to form a single file. One of the attributes for each point in the merged file should contain a count of corresponding time periods on which it falls. For example, if one particular grid point was observed to fall onto the cloud-free portions of six images, then the attribute count of that point in the merged shape file would be six. In the merged file, those points with a count less than two should be discarded (hence the remaining points in the merged file representing "double-coverage"). The number of remaining points should comprise at least 90% of the total number of points within the reference area.

The minimum spatial resolution of the imagery must be 30m. Where possible, multi-spectral imagery should be enhanced using a Tasseled-Cap transformation, Principal Components Analysis (PCA) or other similar transformation to facilitate the differentiation of forest vegetation from other land covers.

The dates of historic imagery should be plotted on a line plot and this plot should be interpreted for stationarity in the time series of imagery (see Figure 3). This is necessary to ensure the estimated time components of the image weights per equation [4] are unbiased. The time series is stationary if the image dates are distributed, on average, across the entire historic reference period.

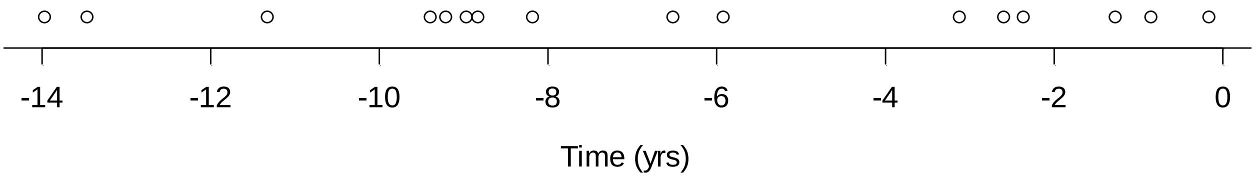

Figure 3: Line plot to demonstrate stationary of historical imagery.
A line plot of the time series of historic images to confirm stationarity. The time series is stationary if the images are well distributed throughout the reference period.

All imagery must be spatially registered to the same coordinate system with accuracy less than 10% Root Mean-Squared Error (RMSE), on average across all images (Congalton, 1991). The accuracy of spatial registration is assessed empirically, each image relative to other collocated images or a ground control point. Oblique imagery should be avoided to maintain accurate spatial registration.

PD Requirements: Historic Imagery to Build the Cumulative Deforestation Model

The project description must include the following:

1. A map of the reference region showing the area of "double-coverage".
2. Quantification of "double coverage"(greater than 90%).
3. A line plot of the historic image dates to confirm stationarity.
4. Empirical evidence that imagery is registered to within 10% RMSE, on average.

6.4.3 Determining Sample Size

A pilot sample of points is distributed across the reference area either randomly or systematically on a grid to estimate the ultimate sample size required to fit the cumulative deforestation model (for an example, see Figure 4). The pilot sample should be large enough to obtain a rough estimate of the population variance. Depending on the size of the reference area and the prevalence of deforestation during the reference period, a good minimum sample size is approximately 100 points in the reference area. If a grid is used, then it must feature a random origin.

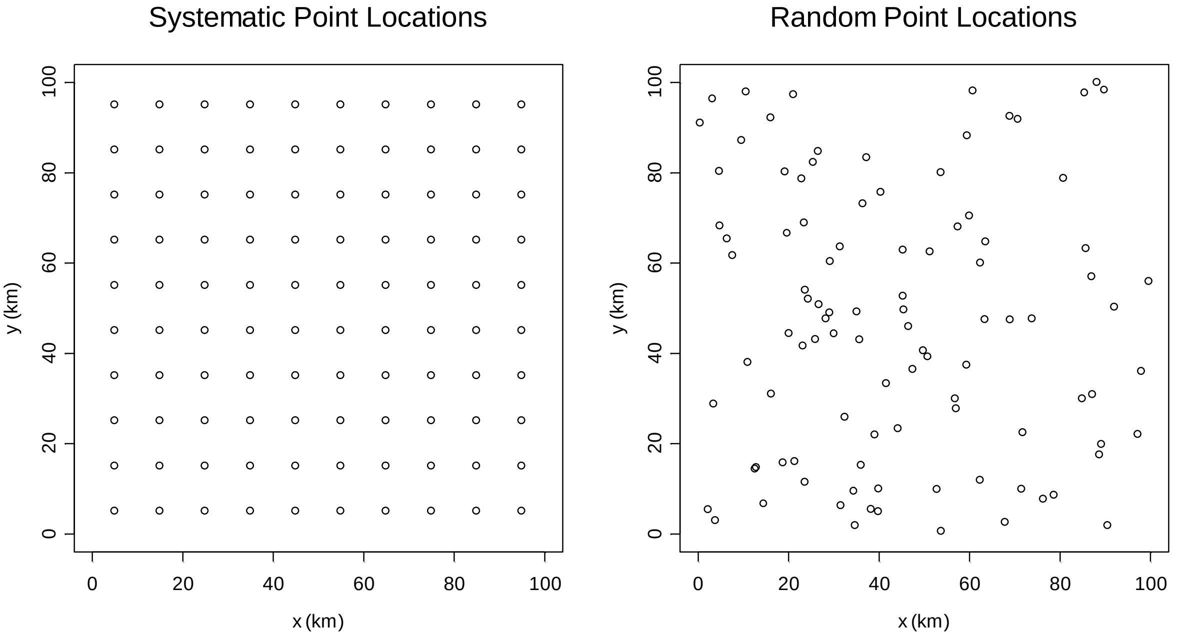

Figure 4: Systematic versus random sampling.
Types of sample points distributed across the example reference area: systematic (left) and random (right).

Forestation is observed at each sample point that falls on the cloud-free portion of each image. Visually interpret all images at each point and record forestation (0 for present or 1 for absent) and the image date in a table, one table for each point, for all points in the pilot sample and all images.

When interpreting a point, use its context to determine the presence of forest. For example, if the point falls onto a pixel and it is unclear whether the pixel is forested, but it is clear that all surrounding pixels are agriculture, its context implies that forest is absent at the point. It is always conservative to interpret forest state as present rather than absent.

For each image, record the number of points that fall on the cloud-free portion in a list.

Next, for each point, sort its table by image date from oldest to most-recent (for example see Figure 5). Discard those points for which the first forestation entry in the table is 1 (forest absent); deforestation cannot be observed without initially observing forest. Each row in each table for each non-discarded point is now an observation as defined by equation [1]. For each row, calculate an observation weight using equation [5] for each state observation where $\#(observations\ at\ x_i, y_i)$ is the number of rows in the table and $\#(observations\ at\ t_i)$ is the number of points recorded in the list for the image with its image date.

Image	Date	State Observation	Weight
1	9/1992	0	0.34045
2	3/1994	0	0.2236
3	3/1995	0	0.54361
4	6/1998	0	0.64526
5	9/1998	1	0.4363
6	7/2001	1	0.62354
7	1/2003	1	0.11469
8	3/2003	1	0.1233
9	1/2005	1	0.63760
10	4/2007	1	0.3548

Figure 5: Table of state observations for a sample point in the reference area.
Table for a non-discarded x_i, y_i sample points sorted by image date.

Next, for each remaining table – one for each non-discarded point – aggregate its rows into a single master table. For each row in the master table, normalize its weight by dividing each weight by the sum of all weights, so that all the weights add to one. The master table may still include locations in the reference area that do not experience deforestation during the reference period.

The master table, constructed from the pilot sample, contains rows that correspond to observations of forest state, observation times and weights. A Horvitz-Thompson estimator of the standard deviation of deforestation state $\hat{\sigma}_{DF}$ in the reference region is given in equation [17] where o_i corresponds to an observed state, $w_i$corresponds to a normalized weight for the i^{th} row and $\mathcal{I}$ is the set of all rows in the master table.

The minimum sample size $\widehat{m}_{DF}$ in the space of the reference area required for fitting the deforestation model is estimated by [6]. This is the number of sample points to be placed in the reference area for fitting the cumulative deforestation model. This number differs from n_{DF} which represents the total number of state observations across both time and space.

6.4.4 Sampling Deforestation

Sampling deforestation to fit the cumulative deforestation model is similar to the procedure for estimating sample size using a pilot sample, except that the deforestation sample size must be at least $\hat{m}_{DF}$. The observed state vector $\boldsymbol{o}$, time vector $\boldsymbol{t}$ and the weight vector $\boldsymbol{w}$ used to fit the model comprise columns of the master table.

PD Requirements: Sampling Deforestation to Build the Cumulative Deforestation Model

The project description must include the following:

1. The sample size.
2. A map of the reference region showing the sample point locations.

6.4.5 Discarded Sample Points

When sampling deforestation in the reference area, some sample points are discarded because their initial observations were non-forest; deforestation cannot be observed without initially observing forest. These points should be discarded indefinitely and should not be used in the leakage assessment or in any baseline reevaluations. Likewise, these points should not be considered when estimating the minimum sample size.

In the master table, an attribute should be retained for all non-discarded sample points so that these sample points can be mapped back to locations in the reference area.

6.4.6 Minimizing Uncertainty

Observation error should be mitigated as much as possible by developing a protocol for the interpretation of forest state from remotely-sensed imagery. Training should ideally be provided to the interpreter(s).

Observation data should be checked for inconsistencies. For example, observations of forest state over time at any one point in space probably do not transition from forest to non-forest, and then back to forest during the reference period (for an example, see Figure 6). A list of "impossible" or "unlikely" forest state transitions should be developed, and each point that matches the criteria should be reexamined.

Image	Date	State Observation
1	9/1992	0
2	3/1994	0
3	3/1995	0
4	6/1998	0
5	9/1998	1
6	7/2001	1
7	1/2003	0
8	3/2003	1
9	1/2005	1
10	4/2007	1

Figure 6: Table of state observations to identify possible errors.
Table for an x_i, y_i sample point featuring a potential interpretive error at image date 1/2003.

A random subset of sampled points should be interpreted independently, and these observations should be checked against the observations made by the interpreter or interpretive team members to identify any systematic misinterpretation. All systematic errors should be corrected.

PD Requirements: Minimizing Uncertainty in the Cumulative Deforestation Model

The project description must include the following:

1. A protocol for interpreting forest state from imagery.
2. The results of an independent check of the interpretation.

6.4.7 Model Fitting and Selection

The model defined by equation [16] is fit using the sample deforestation data from the reference area as well as covariate data for the reference period. The sample deforestation data include the state observation vector $\boldsymbol{o}$ and the time vector $\boldsymbol{t}$. A plot of these vectors shows that states are zeros and ones (for an example, see Figure 7).

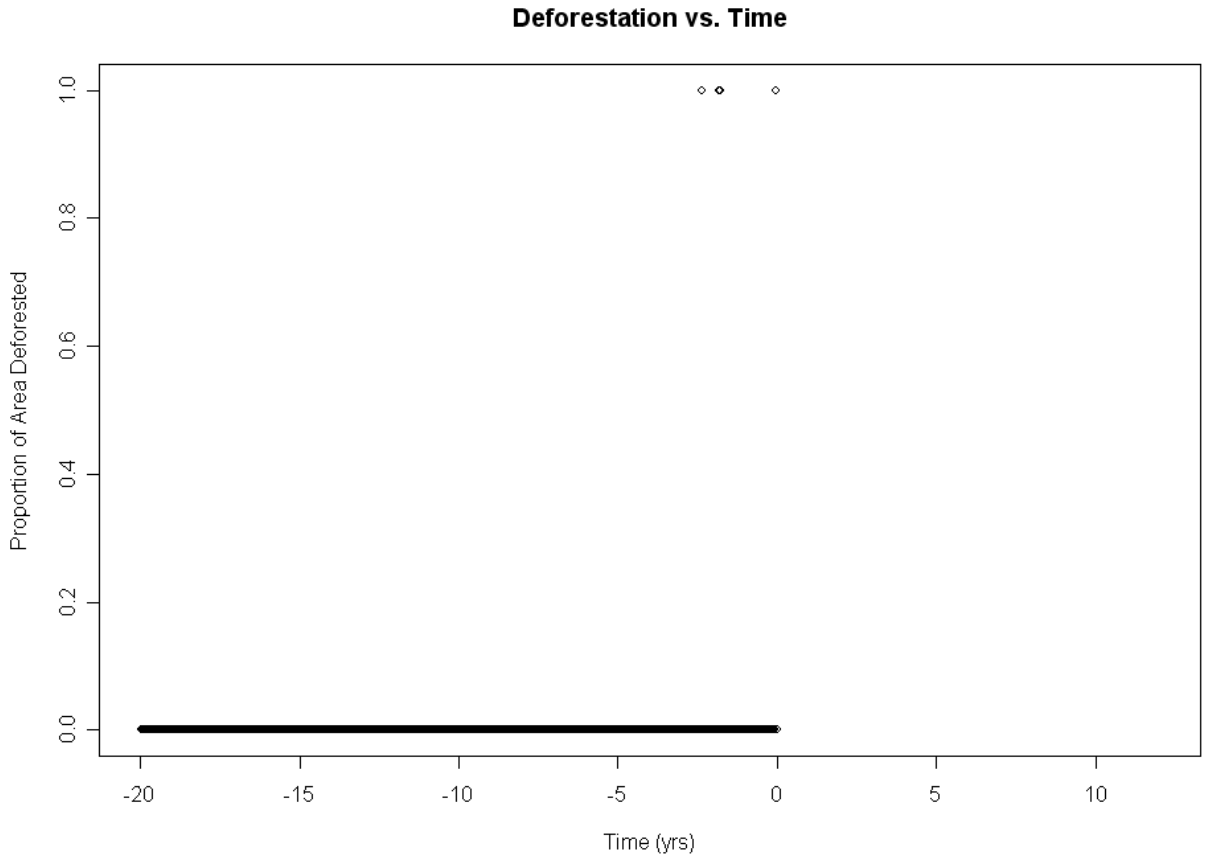

Figure 7: Graph of example state observations.
A graph of the state vector over time for the example reference area showing ones and zeros.

Covariate data are collected for each state at each time period for which there exists imagery. As such, covariate data may need to be interpolated from their sources (e.g. census data that may only be collected once every ten years). These data are used to estimate the linear predictor [7] where $\boldsymbol{\theta}$ is the parameter vector.

$$\eta = \alpha + \beta t + \boldsymbol{\theta} \boldsymbol{x}^T \quad [7]$$

Covariate data must originate from the following sources to avoid the possibility of perverse incentive in model fitting:

- Government publications.
- Publications by an independent third party.
- Peer reviewed literature.

The model is fit using IRLS with an initial weight vector $\boldsymbol{w}$ that corrects for spatial and temporal artifacts from sampling historic imagery (see Venables & Ripley, 2002 for information on model fitting with IRLS).

Given all possible covariates $\boldsymbol{\theta}$, select the best subset of covariates using AIC as a measure of fit. For information on model selection see Davidson (2003) and Freedman (2009). The fit model should be plotted with forest state over time and the project start date (for an example see Figure 8).

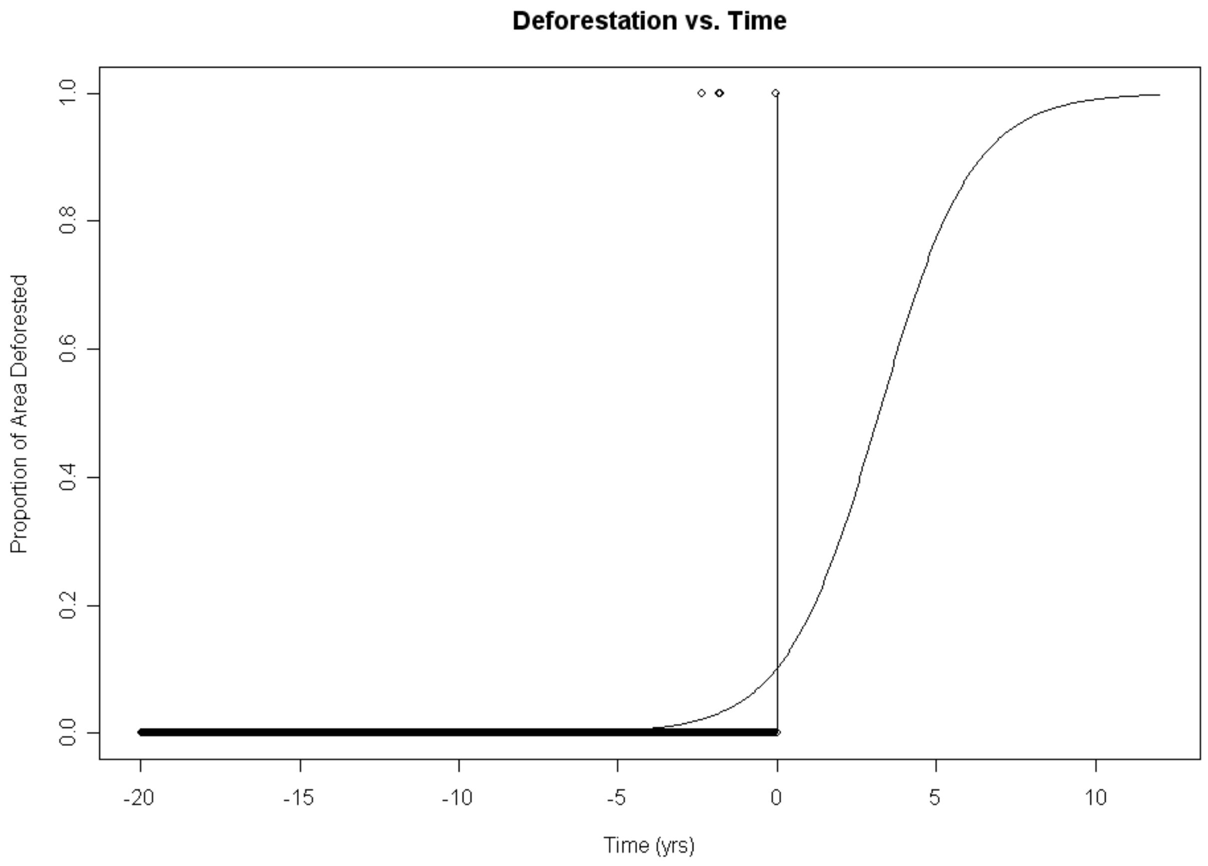

Figure 8: Graph of an example cumulative deforestation model.
A graph of the estimated logistic function over time for the example reference area relative to the project state at time zero.

Once selected and fit, the cumulative deforestation model $F_{DF}(t, \hat{\eta})$ is defined by equation [16].

PD Requirements: Fitting the Cumulative Deforestation Model

The project description must include the following:

1. The covariates that were considered and their data sources.
2. The linear predictors that were evaluated during model selection.
3. The linear predictor of the selected model.
4. The rationale used for selecting this predictor including comparisons of AIC.

6.4.8 Predicting Cumulative Deforestation

A project proponent may be interested in spreading carbon credits over time (e.g. for accounting / cash flow purposes) using a conservative linear model. Therefore, the project proponent may predict proportion deforestation at any point in time using either the parameterized version of [16], which is denoted $F_{DF}(t,\hat{\eta})$, or alternatively may choose any linear rate of deforestation, as long as the linear predictions are conservatively less than $F_{DF}(t,\hat{\eta})$ at any point in time. In the event that a linear rate is selected, $F_{DF}(t,\hat{\eta})$ becomes an upper bound on the maximum deforestation allowable at any point in time. If a linear rate is selected, then the linear prediction of cumulative deforestation should be used in place of $F_{DF}(t,\hat{\eta})$ for accounting purposes.

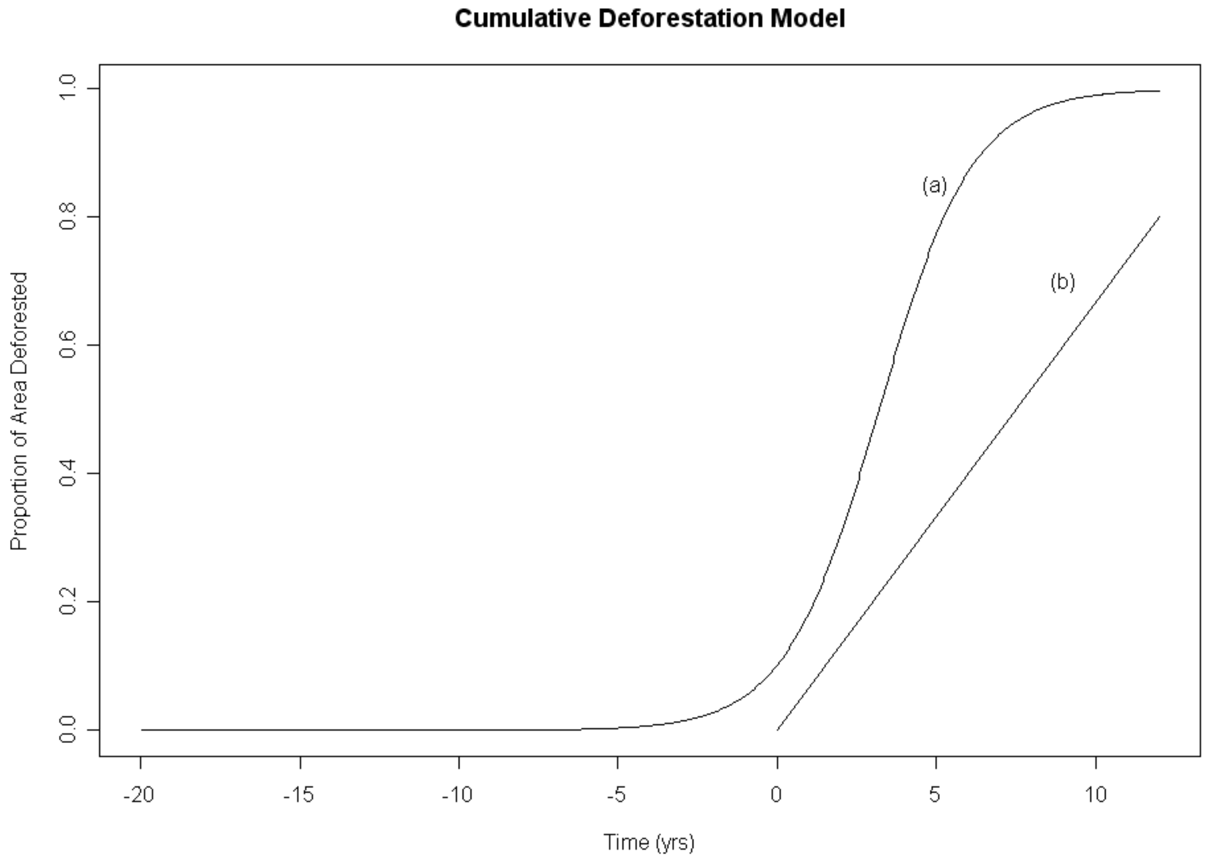

Figure 9: Graph of an example linear rate of deforestation.
A graph of the cumulative deforestation model (a) over time for the example reference area and a linear rate of deforestation (b) selected by the project proponent.

The project proponent may alter the linear rate upon baseline reevaluation or if the selected rate exceeds the predicted cumulative deforestation $F_{DF}(t,\hat{\eta})$ at any point in time (see section 6.7).

PD Requirements: Linear Prediction of Deforestation

If a linear rate is selected, the project description must include the following, per the above criteria:

1. The selected rate, according to the notation depicted in [7].
2. The prediction of $F_{DF}\left(t_2^{[m]}, \hat{\eta}^{[m]}\right)$ for the end date of the current monitoring period.
3. A table of cumulative deforestation used for previous monitoring periods either from equation [16], or the selected linear rate. The cumulative deforestation model should only be refit during a baseline reevaluation (see section 6.7).
4. A graph of $F_{DF}(t, \hat{\eta})$ from the project start date to the end date of the current monitoring period, including points representing cumulative deforestation for previous monitoring periods used to determine baseline emissions either from equation [16] or the selected linear rate.

6.4.9 Estimating Uncertainty in the Cumulative Deforestation Model

Uncertainty in the cumulative deforestation model is estimated from the sample of observed forest states and is used to determine the confidence deduction (see section 11.1). A Horvitz-Thompson estimator of the standard deviation of observed state $\hat{\sigma}_{DF}$ in the reference region is given in equation [17] where o_i corresponds to the observed forest state, w_i to the normalized weight for the i^{th} observation, n_{DF} the total number of state observations and $\mathcal{I}$ the set of all observations made. An approximate estimate of uncertainty at the 95% confidence level is given by [15].

PD Requirements: Estimating Uncertainty in the Cumulative Deforestation Model

The project description must include the following:

1. List of values used for variables in determining the uncertainty in the cumulative deforestation model as they relate to equations [15] and [17].
2. The quantified uncertainty in the cumulative deforestation model.

6.5 Soil Carbon Loss Model

In addition to cumulative deforestation, the baseline scenario ("without-project" scenario) includes the estimated loss of organic carbon from soil over time in the project area as a result of land conversion to agriculture. The soil carbon loss model is either parameterized from observations of soil carbon in the reference area or taken from literature. If neither method is available, the proponent may use a conservative default model presented below. The parameterized model predicts the proportion of carbon loss over a period of time given field observations, and is the preferred method, as it is the most accurate and realistic option.

The soil carbon loss model is only applicable to the soil carbon pool under the baseline.

6.5.1 Background

This background section contains general information about the soil model and the selected approach to fitting the soil model, rather than specific instructions as to how to build the soil carbon loss model.

Literature suggests that the amount of soil (organic matter) carbon loss following forest conversion to cultivation, due to decomposition processes, follows an exponential decay (loss) curve, with the majority of loss occurring within the uppermost soil horizons (e.g. top 20-30 cm) and within the first few years (E. Davidson & Ackerman, 1993). An exponential decay function integrates to cumulative loss, given by [11], where λ represents the *exponential soil C decay parameter* and describes decay of the carbon that will eventually be lost. Project proponents should select an exponential soil decay parameter, λ, from locally appropriate peer-reviewed scientific literature or estimate the parameter, $\hat{\lambda}$, using empirically measured data per Section 6.5.5.1, or utilize the default value. Following deforestation, only a portion of the soil carbon stock is lost, whereby. soil organic carbon stocks decline towards a new equilibrium level over time, reaching some maximum soil carbon loss proportion that ultimately depends on both the depth of the soil column and cultivation practices over time. The depth of the soil column and cultivation practices vary by project; hence, $\hat{\ell}_{max}$must be estimated on a project-by-project basis. Equation [11] can be expressed in terms of this maximum proportion as [13] where $\hat{\ell}_{max}$ represents the maximum soil carbon proportion lost.

A sampling of soil carbon measurements from the reference area is used to estimate $\hat{\ell}_{max}$ using a process known as a "space for time substitution" which assumes that soil C stocks in the reference area (that has been previously deforested) are representative of the soil C levels that would be obtained over time in the project area if it were to be deforested and converted to cropland use.. Assuming that the sample data are obtained from soil columns with equal depth and that the data are collected from agricultural soils of known age, then the sample mean should be used to estimate $\hat{\ell}_{max}$, per equation [12]. It should be noted that this text does not explicitly prescribe a duration of time required to accurately derive a value for $\hat{\ell}_{max}$. The authors were purposely inexplicit in this regard, as it is in the proponent's best interest to collect data that purportedly represents a period of time after the soil carbon stock has reached a new equilibrium state (no longer declining). If $\hat{\ell}_{max}$is derived from agricultural fields that are "too recent", clearly the estimate of proportional soil loss, $\hat{\ell}_{max}$, will be biased toward less decay than may ultimately occur. It is therefore recommended to sample in farms between 5 and 20 years in age to capture complete soil carbon decay in tropical ecosystems.

6.5.2 Building the Soil Carbon Loss Model

The soil carbon loss model is a necessary tool to predict the decay of soil organic carbon in the project area under the baseline scenario, i.e., losses that would have occurred after deforestation in the without-project scenario. The model is constructed by measuring soil organic carbon at a sampling of cultivated areas, *of known age*, in the reference area. The mean of these measurements from the reference area is divided by the mean value of soil organic carbon inside the project area (tonnes CO2e) to estimate $\hat{\ell}_{max}$. The model can use either $\lambda = 0.2$ as a conservative default, or a value for $\hat{\lambda}$ derived from project-specific, empirical measurements, calculated as per section 6.5.5.1, that is then applied to [11] along with the estimated maximum soil carbon loss proportion $\hat{\ell}_{max}$. A third option is also presented in section 6.5.5, which allows for the use of appropriate peer-reviewed literature to build the loss model. Any studies used for this option must feature conditions the same as, or similar to, the project reference area, as specified in section 6.3.

6.5.3 Sampling Soil Carbon Loss

Soil carbon is measured using a purposive sample of farms in the reference area. Project proponents should take care to ensure that the sampling scheme incorporates all types of agricultural conditions and states that occur within the reference area (i.e. fallow fields, active fields, etc.) To derive a representative sample and reduce uncertainty, it is recommended that the reference area be stratified by appropriate variables (e.g. soil taxonomic class, landscape position) and the ensuing sampling scheme be designed according to these strata. A stratified random approach is suggested in order to achieve maximum explanation of agricultural variance in the reference area. It is further suggested that samples are taken from similar strata in the project area and reference area, so as to achieve an accurate comparison of different land use types present in the project ecosystem. Further guidance on sample allocation (e.g. Neyman allocation) can be found in section 13.3.1 'Determining the Sample Size'.

Samples may be extracted using a soil core or by digging a soil pit. Because of the high degree of spatial variability in soil carbon stocks, it is recommended that several samples be taken from different randomly selected locations within each farm and mixed prior to measurement in the laboratory or several samples for different soil horizons be analyzed separately, and analysis results combined after-the-fact. If soil pits are used, multiple horizons should be extracted (at least 3 are recommended) to ensure that the soil is being measured to a sufficient spatial resolution along its depth. Bulk density and carbon concentration should be measured for each individual soil horizon, as it is important to apply these individual measurements to achieve mass-equivalent measurement. Bulk density and carbon concentration should be evaluated by a laboratory that follows internationally recognized standards (e.g. FAO standards) to minimize errors and bias. A consistent total depth for soil sampling should be established, and this depth should be no less than the depth to which soil is disturbed during farming, typically a minimum of 30cm.. Compute the soil carbon stock for each sample y_i using equations [60] and [61] as described in section 13.9. If bulk density for the within-project measurements differs significantly from the reference area measurements, and where appropriate, measurements should be evaluated on a mass-equivalent basis (see references below). Enough samples should be taken to ensure a statistically defensible result. As similarly stated in section 13.9 'Estimating Carbon in Soil', care should be taken to synthesize samples collected both within the project area and in the reference area. In particular, it is important to sample soil to the same depth both within the project and in the reference area, typically a minimum of 30cm, and also to ensure that data is evaluated on a mass-equivalent basis, as directed by (Ellert, Janzen & Entz, 2002; Ellert & Bettany, 1995).

PD Requirements: Sampling Soil Carbon Loss

The project description must include the following:

1. A map of the reference area showing the locations of the farms selected for sampling. If no field samples are taken (i.e., soil C is an excluded pool), this requirement is relaxed.
2. The selected depth for soil sampling should be no less than the depth to which soil is disturbed during farming and a rationale for selecting this depth should be provided.
3. A table with the collected data including bulk density, soil carbon, proportion soil carbon lost and length of time since conversion. If no field samples are taken, this requirement is relaxed.
4. A description of soil types in the reference area and in the project area and justification of the similarity of soils sampled to soils in the project area. The description may include soil maps, if available.

6.5.4 Minimizing Uncertainty

Uncertainty in measurement should be reduced as much as possible by developing an appropriate field protocol for sampling soil carbon. This protocol may be identical to the protocol used to sample soil for project monitoring. As field protocol may differ between projects, specialized training should be provided to collection teams.

PD Requirements: Minimizing Uncertainty in the Soil Carbon Loss Model

The project description must include the following:

1. A protocol (SOP) for field sampling soil carbon.
2. Evidence of training for field collection teams.

6.5.5 Model Fitting

The model defined by equation [18] is fit by estimating the maximum soil carbon loss proportion $\hat{\ell}_{max}$ using the soil carbon measurements from sampled farms in the reference area. Determine $\hat{\ell}_{max}$ as the sum of each observation y_i, the measured soil carbon stock per unit area for each sample in the reference area, over the set of all samples $\mathcal{A}$ (weighted by strata area if the reference area is stratified), divided by the stratified average of soil carbon as estimated for the project area as defined by equation [12]. A particular $\hat{\lambda}$ is applied to equation [18] as the parameterized soil carbon loss model $S(t_1, t_2, \hat{\lambda}, \hat{\ell}_{max})$. A conservative default value of $\lambda = 0.2$, based on limited published data for tropical systems (Davidson & Ackerman, 1993), is recommended if a project-specific estimate for λ is not used. A graph of [11] with λ = 0.20, and the maximum soil carbon proportion lost, $\hat{\ell}_{max}$ = 0.49, is shown below in Figure 10. Please note that this plot is presented solely as an illustrative example. The plot uses fictitious data, and should not be applied directly without deriving or estimating individually appropriate values for both the soil decay parameter and the maximum soil carbon proportion lost on a per-project basis.

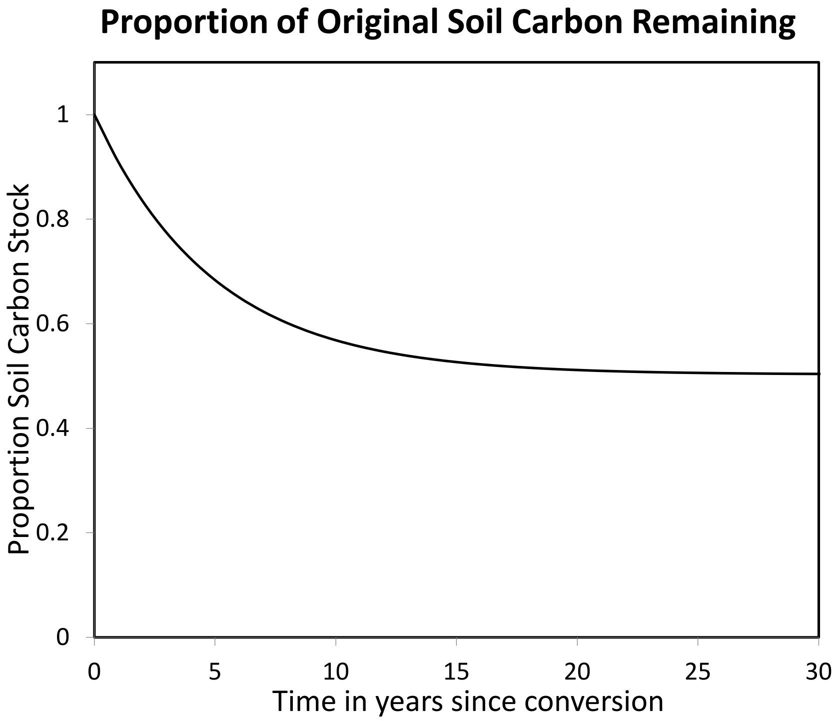

Figure 10: Graph of theoretical soil carbon loss.
A graph of theoretical soil carbon loss based on exponential decay, with λ =0.20

If a value for λ or $\hat{\lambda}$ is selected which is higher than the default of 0.20, then it must be justified by the project proponent based on data from at least one of the following sources:

- Government publications.
- Publications by an independent third party.
- Peer reviewed literature.
- Field measurements taken in the reference area, as described below.

6.5.5.1 Empirically Estimating $\hat{\lambda}$

In order for the project proponent to estimate the exponential soil decay parameter, $\hat{\lambda}$, from empirically measured data, the project proponent must perform a "space for time" substitution, as it is impractical to repeatedly sample the same recently-converted forest patch over the project crediting period (required to generate enough measurements to derive a soil decay curve). The space for time substitution allows the project proponent to make many measurements at the same point in time, over a range of agricultural fields, distributed spatially within the reference area, that were converted from forest at *known times*.

Given adequate expert knowledge of the reference area, including knowledge of farming practices and culture, the project proponent may apply empirically measured soil carbon results to mathematically derive a value for lambda. This should involve a statistically sound method such as temporal regression or trend analysis, and must be accepted by the validator at project validation.

If the project proponent opts to measure soil carbon loss empirically, measurements must be taken within the same reference area that meets the requirements listed in section 6.3 and 6.5. This serves to ensure that parameterization of the soil model is representative of common farming practices in the region.

6.5.6 Predicting Soil Carbon Loss

Soil carbon loss as a proportion of original soil carbon is estimated using $S(t_1, t_2, \hat{\lambda}, \hat{\ell}_{max})$ between any two times from t_1 to t_2 as defined by equation [18].

PD Requirements: Predicting Soil Carbon Loss

The project description must include the following:

1. A graph of equation [13] (theoretical model) or an empirically measured model.
2. A description of the loss of carbon from soils in the project area over time.

6.5.7 Estimating Uncertainty in the Soil Carbon Loss Model

Uncertainty in the soil carbon loss model is estimated from the sample of soil carbon stocks in the reference area (see section 6.5.3) and is used to determine the confidence deduction (see section 11.1). Uncertainty at the 95% confidence level is estimated as equation [19] where $\hat{\sigma}_{SCL}$ and n_{SCL} are the standard deviation and total number of soil samples taken in the reference area used to estimate the asymptotic soil carbon loss, respectively.

PD Requirements: Estimating Uncertainty in the Soil Carbon Loss Model

The project description must include the following:

1. The quantified uncertainty in the soil carbon loss model.

6.6 Baseline Scenarios for Selected Carbon Pools

The following sections describe how the baseline models are applied to each pool and any additional assumptions used in determining baseline emissions.

6.6.1 Scenario for Above-ground Large Trees

The above-ground portions of large trees are assumed to be removed, burned or converted to fuel wood or long-lived wood products as a result of land conversion to agriculture. The proportion of above-ground large trees that is converted to long-lived wood products is addressed under the scenario for wood products. The baseline scenario for above-ground large trees is directly related to the cumulative deforestation model which predicts the proportion deforestation over time and the decay of wood products over time.

6.6.2 Scenario for Above-ground Small Trees

The above-ground portions of small trees are assumed to be removed, burned or converted to fuel wood as a result of land conversion to agriculture. Unlike large trees, it is assumed that small trees are not converted to long-lived wood products. The baseline scenario for above-ground small trees is directly related to the cumulative deforestation model which predicts the proportion of deforestation over time.

6.6.3 Scenario for Above-ground Non-trees

The above-ground portions of non-trees are assumed to be removed, burned or converted to fuel wood as a result of land conversion to agriculture. Like small trees, it is assumed that non-trees are not converted to long-lived wood products. The baseline scenario for above-ground non-trees is directly related to the cumulative deforestation model which predicts the proportion deforestation over time.

6.6.4 Scenario for Below-ground Large Trees

The below-ground portions of large trees are assumed to be partially removed, burned or converted to fuel wood as a result of land conversion to agriculture. The proportion of below-ground large trees that is removed as a result of land conversion to agriculture p_{BGLT} must be selected by the project proponent where the balance of below-ground biomass not removed is assumed to remain over the life of the project or longer. This proportion will probably be selected based on empirical evidence observed in the region and will likely vary from project to project depending on the mechanism used to clear the land. For instance, if a mechanical device is used to clear the forest, such as a bulldozer, then this proportion might be higher than if the forest is cleared with a handsaw.

The baseline scenario for below-ground large trees is directly related to the cumulative deforestation model which predicts the proportion deforestation over time. This proportion may be one if all below-ground large tree biomass is removed as a result of land conversion to agriculture

PD Requirements: Selecting the Proportion of Below-ground Biomass Removed from Large Trees

The project document must include the following:

1. The selected proportion of below-ground large tree biomass that is removed as a result of land conversion to agriculture, p_{BGLT}.
2. Rationale for selecting this proportion.

6.6.5 Scenario for Below-ground Small Trees

The below-ground portions of small trees are assumed to be completely removed, burned or converted to fuel wood as a result of land conversion to agriculture. The baseline scenario for below-ground small trees is directly related to the cumulative deforestation model which predicts the proportion deforestation over time.

6.6.6 Scenario for Below-ground Non-trees

The below-ground portions of non-trees are assumed to be completely removed, burned or converted to fuel wood as a result of land conversion to agriculture. The baseline scenario for below-ground non-trees is directly related to the cumulative deforestation model which predicts the proportion deforestation over time.

6.6.7 Scenario for Standing Deadwood

Standing deadwood is assumed to be completely removed, burned or converted to fuel wood as a result of land conversion to agriculture. The baseline scenario for standing deadwood is directly related to the cumulative deforestation model which predicts the proportion deforestation over time.

6.6.8 Scenario for Lying Dead Wood

Lying deadwood is assumed to be completely removed, burned or converted to fuel wood as a result of land conversion to agriculture. The baseline scenario for lying deadwood is directly related to the cumulative deforestation model which predicts the proportion deforestation over time.

6.6.9 Scenario for Soil

Soil is assumed to lose its organic carbon over time as a result of agriculture (E. Davidson & Ackerman, 1993). The baseline scenario for soil carbon is directly related to the cumulative deforestation model which predicts the proportion deforestation over time and the soil carbon loss model which predicts the loss of organic soil carbon over time.

6.6.10 Scenario for Wood Products

The carbon proportion of long-lived wood products from the harvesting of above-ground large trees is conservatively assumed to remain sequestered throughout the lifetime of the project crediting period. The carbon sequestered in long-lived wood products under the baseline scenario is assumed to be a proportion of the baseline emissions $r_{WP}$and it must be selected by the project proponent. The project proponent may select a zero proportion if no long-lived wood products are harvested under the baseline scenario.

Methods for estimating this proportion include those adaptable from Lim, Brown, & Schlamadinger 1999; Pearson, Brown, & Birdsey 2007; Winjum, Brown, & Schlamadinger 1998. Appropriate methods to select this proportion include but are not limited to household surveys, scaling national or regional data to the project level, and estimating wood product biomass as the difference between biomass loss and carbon emitted through land conversion. The project developer must demonstrate that the selected proportion is both conservative and appropriate for the reference region.

PD Requirements: Selecting the Proportion of Wood Products

The project description must include the following:

1. The proportion of baseline emissions that are stored in long-lived wood products, r_{WP}.
2. Rationale for selecting this proportion.

6.7 Baseline Reevaluation

The baseline scenario must be reevaluated per current VCS requirement (VCS, 2008a). Baseline reevaluation may include the following:

- Conduct a new participatory rural survey and subsequent analyses.
- Reevaluate the boundaries of the reference area and delineate new boundaries to exclude any new REDD projects or additions to the project area, based on the results of the new participatory rural survey.
- Reevaluate the reference period – the new period should reflect the time since the project start date or the last baseline reevaluation.
- Add new observations of forest state and refit the cumulative deforestation model.
- Perform model selection using updated covariate data.
- Chose to select a new linear rate per section 6.4.8.
- Refit the leakage model per section 10.3.3.

During baseline reevaluation, the historic reference period is extended to include the original reference period and all subsequent monitoring periods up to the beginning of the current monitoring period. The latter of these periods is called the reevaluation period. The agents and drivers of deforestation should be reanalyzed (see sections 6.2.1 and 6.2.2), and the boundaries of the reference area should be re-delineated, if necessary, to produce a new reference area for the reevaluation period (see section 6.3.1). When choosing the new reference area, the mobility of the agents and drivers of deforestation and the degree of leakage identified over previous monitoring periods should be considered and any areas subject to leakage should be excluded from the reference area. If leakage has been observed, this may require the exclusion of all or part of the leakage area from the area used to reevaluate the baseline. Compared to the reference area prior to the reevaluation period, portions might be excluded or new areas might be included. For example, if during the reevaluation period, a portion of land along a river which was part of the original reference area was designated for community development by the local government, the agents and drivers of deforestation on this portion of land may have changed and subsequently the land should be excluded from the reference area for the reevaluation period.

After the new reference area is delineated, the cumulative deforestation model is reconstructed using both the observations made prior to the reevaluation period and new observation of deforestation made during the reevaluation period. Deforestation is sampled during the reevaluation period using the new reference area per section 6.4.4 (for example, see Figure 11). The original covariates (numeric drivers of deforestation) may change as a result of model selection – those covariates that best predict deforestation should always be used.

As shown in Figure 11, the new and old cumulative deforestation models may not be continuous at the time of baseline reevaluation. Subsequent to baseline reevaluation, just as prior to baseline reevaluation with the old model, the project proponent must select a level of cumulative deforestation that is below the level predicted by the new model. This level could derive from a selected linear rate per section 6.4.8. If the new cumulative deforestation model is below the old model and credits have been issued at a level above that predicted by the new model, then the project proponent may not generate new credits from deforestation until the new model predicts a level greater than or equal to the level used to determine the last issuance of credits from avoided deforestation. In this event, only credits from forest growth can be generated until the new model reaches the previous level used for crediting. This event does not constitute a reversal unless it occurs at the end of the project crediting period (see section 11.2).

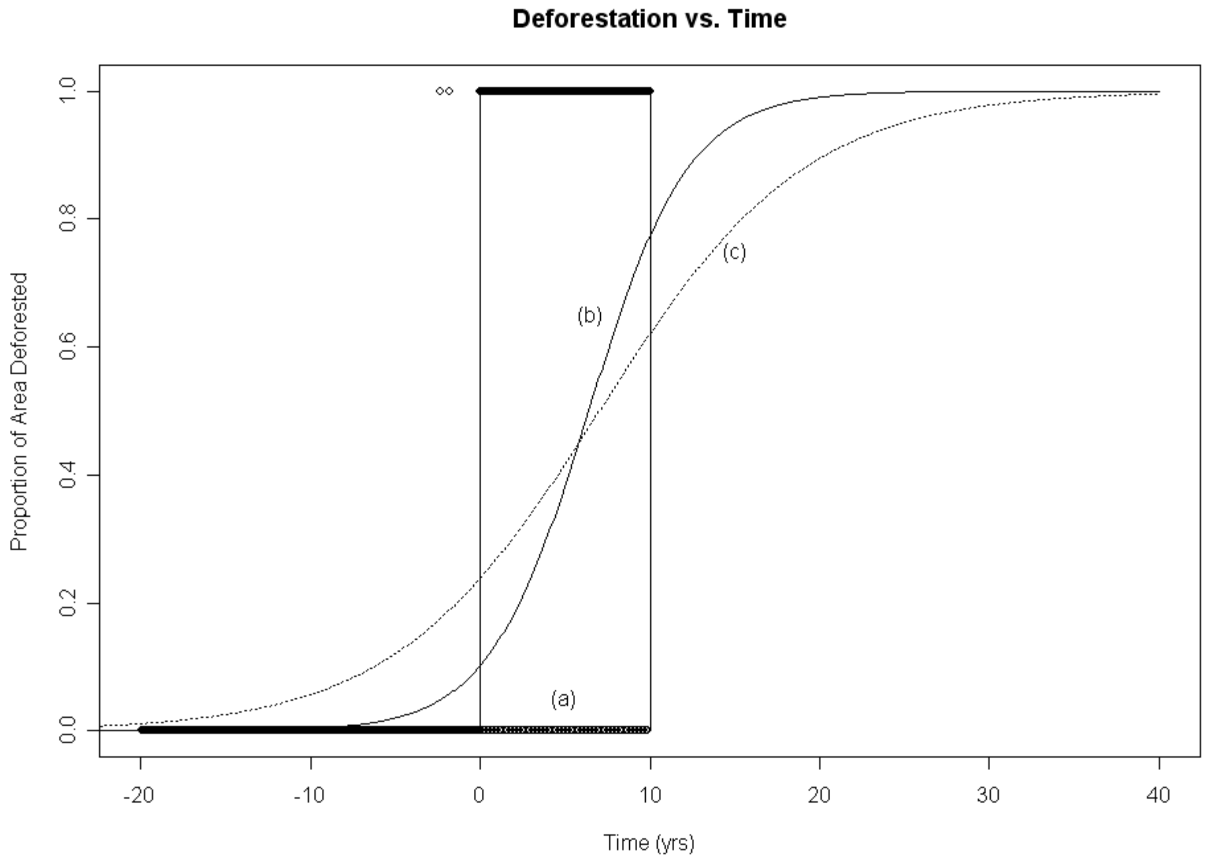

Figure 11: Graph of an example baseline reevaluation.
The first reevaluation period since the project start date at time zero (a), the original cumulative deforestation model (b) and the reconstructed model using additional observations (dashed) from the new reference area (c).

The soil carbon loss model does not need to be reevaluated, as post conversion carbon loss follows a single model.

PD Requirements: Baseline Reevaluation

Upon a baseline revision, the project description must include the following as of the current monitoring period:

1. All required documentation as specified in section 6 for the project prior to the baseline reevaluation.
2. All required documentation as specified in section 6 for the project after the baseline reevaluation including the reevaluation period.
3. A narrative of the reevaluation including any obstacles and how they were overcome.

7 Additionality

Project proponents shall demonstrate additionality using the latest version of the VCS “Tool for the Demonstration and Assessment of Additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities” (VCS, 2010b). Relevant applicability conditions (see section 4) for this methodology are as follows:

- Within the project area, project activities shall not lead to the violation of any law, even those laws which are not enforced.
- The most conservative baseline scenario is defined by deforestation / conversion to agriculture.

The common practice test must demonstrate that project activities will address at least one driver of deforestation in such a way that the driver would not have been adequately addressed had the project not been undertaken.

PD Requirements: Demonstration of Project Additionality

The project description must include the following:

1. A list of alternative land use scenarios to the project.
2. Justification for the selected baseline scenario of deforestation/ conversion to agriculture. This justification can include expert knowledge, results from the participatory rural appraisal and the cumulative deforestation model (see sections 6.2 and 6.4).
3. An investment or barriers analysis (VCS, 2010b) proving that the project is not the most economical option.
4. A common practice analysis (VCS, 2010b) including a list of project activities and the drivers of deforestation that they address.
5. Evident compliance with the minimum requirements of the aforementioned VCS tool. This evidence may be the same as the evidence provided to meet reporting requirements listed in section 4.

8 Baseline Emissions

For any monitoring period, baseline emissions $C_{BE}^{[m]}$ are a sum of estimated emissions over selected carbon pools as defined by [20].

PD Requirements: Baseline Emissions

The project description must include the following:

1. Estimates of baseline emissions for each selected carbon pool.

It is conservative to ignore baseline emissions from degradation so these accounting procedures only consider those emissions from deforestation.

8.1 Estimating Emissions from Above-ground Large Tree Biomass

For any given monitoring period, emissions from above-ground large tree biomass are estimated as a proportion of measured carbon in above-ground large tree biomass at the end point in time of the monitoring period. Measured carbon at period $[m]$ in above-ground large tree biomass is $C_{AGLT}^{[m]}$ (see section 13.5.1). This proportion $F_{DF}(t, \hat{\eta})$ is estimated by the cumulative deforestation model at the end time of the monitoring period (see section 6.4.8). Emissions from above-ground large tree biomass are estimated as [21].

8.2 Estimating Emissions from Above-ground Small Tree Biomass

For any monitoring period, emissions from above-ground small tree biomass are estimated as a proportion of measured carbon in above-ground small tree biomass at the end point in time of the monitoring period. Measured carbon at period $[m]$ in above-ground small tree biomass is $C_{AGST}^{[m]}$ (see section 13.5.2). This proportion $F_{DF}(t, \hat{\eta})$ is estimated by the cumulative deforestation model at the end time of the monitoring period (see section 6.4.8). Emissions from above-ground small tree biomass are estimated as [22].

8.3 Estimating Emissions from Above-ground Non-tree Biomass

For any monitoring period, emissions from above-ground non-tree biomass are estimated as a proportion of measured carbon in above-ground non-tree biomass at the end point in time of the monitoring period. Measured carbon at period $[m]$ in above-ground non- tree biomass is $C_{AGNT}^{[m]}$ (see section 13.5.3). This proportion $F_{DF}(t, \hat{\eta})$ is estimated by the cumulative deforestation model at the end time of the monitoring period (see section 6.4.8). Emissions from above-ground non-tree biomass are estimated as [23].

8.4 Estimating Emissions from Below-ground Large Tree Biomass

For any monitoring period, emissions from below-ground large tree biomass are estimated as a proportion of measured carbon in below-ground large tree biomass at the end point in time of the monitoring period. Measured carbon at period $[m]$ in below-ground large tree biomass is $C_{BGLT}^{[m]}$ (see section 13.6.1). This proportion $F_{DF}(t, \hat{\eta})$ is estimated by the cumulative deforestation model at the end time of the monitoring period (see section 6.4.8). Emissions from below-ground large tree biomass are estimated as [24] where p_{BGLT} is the proportion of below-ground large tree biomass removed as a result of land conversion to agriculture. The project proponent must select this proportion as described in 6.6.4.

8.5 Estimating Emissions from Below-ground Small Tree Biomass

For any monitoring period, emissions from below-ground small tree biomass are estimated as a proportion of measured carbon in below-ground small tree biomass at the end point in time of the monitoring period. Measured carbon at period $[m]$ in below-ground small tree biomass is $C_{BGST}^{[m]}$ (see section 13.6.2). This proportion $F_{DF}(t, \hat{\eta})$ is estimated by the cumulative deforestation model at the end time of the monitoring period (see section 6.4.8). Emissions from below-ground small tree biomass are estimated as [25]. It is assumed that all below-ground small tree biomass is immediately lost as a result of land conversion to agriculture.

8.6 Estimating Emissions from Below-ground Non-tree Biomass

For any monitoring period, emissions from below-ground non-tree biomass are estimated as a proportion of measured carbon in below-ground non-tree biomass at the end point in time of the monitoring period. Measured carbon at period $[m]$ in below-ground non-tree biomass is $C_{BGNT}^{[m]}$ (see section 13.6.3). This proportion $F_{DF}(t, \hat{\eta})$ is estimated by the cumulative deforestation model at the end time of the monitoring period (see section 6.4.8). Emissions from below-ground non-tree biomass are estimated as [26]. It is assumed that all below-ground non-tree biomass is immediately lost as a result of land conversion to agriculture.

8.7 Estimating Emissions from Standing Dead Wood

For any monitoring period, emissions from standing dead wood are estimated as a proportion of measured carbon in standing dead wood at the end point in time of the monitoring period. Measured carbon at period $[m]$ in standing dead wood is $C_{SDW}^{[m]}$ (see section 13.7). This proportion $F_{DF}(t, \hat{\eta})$ is estimated by the cumulative deforestation model at the end time of the monitoring period (see section 6.4.8). Emissions from standing dead wood are estimated as [27].

8.8 Estimating Emissions from Lying Dead Wood

For any monitoring period, emissions from lying dead wood are estimated as a proportion of measured carbon in lying dead wood at the end point in time of the monitoring period. Measured carbon at period $[m]$ in lying dead wood is $C_{LDW}^{[m]}$ (see section 13.8). This proportion $F_{DF}(t, \hat{\eta})$ is estimated by the cumulative deforestation model at the end time of the monitoring period (see section 6.4.8). Emissions from lying dead wood are estimated as [28].

8.9 Estimating Emissions from Soil

For any monitoring period, emissions from soil are estimated as a proportion of measured carbon in soil at the end point in time of the monitoring period. Measured carbon at period $[m]$ in soil is $C_{SOIL}^{[m]}$ (see section 13.9). This proportion is a product of $F_{DF}(t, \hat{\eta})$ which is the estimated cumulative deforestation model and $S\left(t_1^{[m]}, t_2^{[m]}, \hat{\lambda}\right)$ which is the estimated soil carbon loss model during the monitoring period (see sections 6.4.8see section 6.5.6). Emissions from soil are estimated as [29] where $\mathcal{M}$ is the set of all previous monitoring periods including the current monitoring period.

8.10 Estimating Emissions from Wood Products

The project developer must provide an estimate of carbon sequestered in long-lived wood products under the baseline. This estimate is a based on the proportion of above-ground large tree biomass that goes into long-lived wood products as a result of deforestation. Sequestered emissions are estimated as [30] where r_{WP} is the fraction of above-ground tree biomass that goes to wood products. The project proponent must select this proportion as described in section 6.6.10 and is assumed to have remained constant though the project crediting period. The proportion of above-ground large tree biomass that goes into long-lived wood products as a result of deforestation can be zero.

9 Project Emissions

Project emissions for any monitoring period $[m]$ are estimated by the events of woody biomass consumption.

Emissions from forest fires within the project area are inherently captured by the monitoring of forest carbon stocks. Nevertheless, maps of significant fire events are necessary to aid verification of carbon stock estimates but no additional accounting is required. However, the project area may need to be re-stratified per section 13.2.

PD Requirements: Forest Fires

The project description must include the following:

1. A map of the boundaries of any significant forest fires in the project area during the monitoring period.

9.1 Emissions from Burning

Emissions from the burning of woody biomass as a result of project activities in the project area should be recorded as the weight (in tonnes) of woody biomass consumed during each burning event. If the production of sustainable charcoal occurs within the project area, then it must be accounted for under emissions from burning. Emissions from the controlled burning of woody biomass is the sum of all burning events $\mathcal{E}$ during the monitoring period as defined by [31] where cf_{SP} is the carbon fraction of wood for a species.

PD Requirements: Emissions from Burning

The project description must include the following:

1. A table of events when woody biomass was burned during the monitoring period, showing the weight of woody biomass in tonnes and the date consumed.

10 Leakage

This methodology quantifies NERs from avoided deforestation and conservatively excludes avoided degradation from project accounting. However, it is not considered conservative to exclude degradation from leakage assessment. Consequently, leakage is quantified as emissions from both forest degradation and deforestation caused by activities displaced from the project area due to the presence of the project. Degradation activities include the removal of biomass for fuel wood, charcoal production and harvesting of large trees for wood products.

Emissions from non-market leakage are estimated using a cumulative model of combined deforestation and degradation called a leakage model and observations from a leakage area during each monitoring period. The leakage model is developed from the cumulative deforestation model, assuming that degradation precedes deforestation by a lag period, and represents the combined deforestation and degradation expected in the leakage area in the absence of the project. Leakage is assessed at each monitoring period by sampling the leakage area for degradation and deforestation and comparing the observed deforestation and degradation to that predicted by the leakage model. Any observed deforestation or degradation greater than that predicted by the model is considered leakage and is deducted from project crediting. The leakage model is a type of baseline model for the leakage area. It does not predict leakage directly; rather leakage is estimated based on the difference between the prediction of the leakage model and the results of a sample taken at each monitoring period. This process is called leakage assessment and leads to the estimation of a parameter called a leakage factor. The leakage factor is applied to baseline emissions to estimate leakage at any monitoring period.

After the leakage factor has been estimated, emissions from leakage are quantified using equation [32]. Developers should refer to the latest version of the *VCS Tool for AFOLU Methodological Issues* to determine if leakage credit adjustments are necessary (VCS, 2008b).

10.1 Leakage Mitigation Strategies

Projects must include activities designed to reduce deforestation that results from at least one of the drivers identified in section 6.2.2. The types of activities most appropriate vary based on the specific drivers identified, as well as local socio-economic conditions. Examples of these activities may include, but are not limited to:

- Developing economic opportunities for local communities that encourage protection, such as employment as protected-area guards or ecotourism guides
- Developing alternative incomes not derived from forest destruction
- Introducing improved agricultural practices that result in a decreased demand for newly cleared land
- Developing sustainable means of producing fuel wood

Project activities must be monitored in some way to demonstrate their effect on leakage mitigation. Possible monitoring approaches vary by project and may include:

- The number of people that directly benefit from the activity.
- The number of units distributed as a result of an activity (such as number of trees, foodstuffs, vaccines or dollars).
- The time devoted to implementing an activity.
- Community surveys about the effectiveness of an activity.

PD Requirements: Leakage Mitigation Strategies

The project description must include the following:

1. A list of project activities designed to mitigate leakage.
2. A description of project activities that have been implemented since the project start date and the estimated effects of these activities on leakage mitigation.

10.2 Delineating the Leakage Area

The leakage area:

1. must be in the same general region as the project area, but not necessarily adjacent to the project area,
2. must be at least the size of the forested portions of the project area but does not need to be contiguous with the project area,
3. may not include any part of the project area but may either entirely or partially overlap the reference area,
4. must be entirely forested as of the project start date.

The boundaries and size of the leakage area should address the following criteria:

1. Proximity to the project area: The leakage area should be near the project area. This distance varies project-to-project depending on the location of the agents of deforestation acting on the project area.
2. The location of the agents of deforestation acting directly on the project area. The leakage area should be as close to the location of the agents of deforestation as it is to the project area.
3. The mobility of the agents of deforestation acting directly on the project area. The entire leakage area should be accessible to the agents of deforestation.
4. The direction that activities are likely to shift. For example, the pattern may be from east to west and therefore the leakage area might be located on the western side of the project area.
5. Landscape configuration including the following:
    a. Topographic constraints to deforestation (slope, aspect, elevation);
    b. Land use and/or land cover constraints to deforestation;
    c. Access points that may constrain deforestation;
    d. Areas of limited soil productivity; and
    e. Ownership/tenure boundaries that constrain deforestation (government holdings, private holdings and reserves).
6. The leakage area must be as constrained by landscape configuration as the project area.

The interpretation of these criteria is subjective and the project proponent should always choose boundaries that result in the most conservative estimates of leakage. That is, given a choice of reasonable leakage areas, chose the area that will likely yield the highest estimate of leakage whether or not the estimated leakage is entirely attributable to activity-shifts from the project area. The following analyses may be helpful to identify the boundaries and size of the leakage area:

- Buffering the boundaries of the project area.
- Mapping the locations of agents of deforestation.
- Buffering the locations of agents based on the distance of their mobility.
- Mapping the locations of important cultural places.
- Digital elevation models.
- Maps of topographic surveys.
- Maps of land use and land cover.
- Mapping the locations of access points that may constrain deforestation.
- Maps of soil productivity.
- Maps of ownership boundaries (government holdings, private holdings and reserves).

PD Requirements: Delineation of the Leakage Area

The project description must include the following information with respect to the leakage area:

1. A map of the delineated boundaries.
2. A thematic map or image of the leakage area showing that it was entirely forested as of the project start date.
3. The size of the forested portion of the project area and the size of the leakage area.
4. A narrative describing the rationale for selection of leakage area boundaries.

10.3 The Leakage Model

To estimate leakage, a model of the cumulative biomass loss that would occur as a result of deforestation and degradation in the absence of the project is required. Because both degradation and deforestation are included in this scenario, the biomass loss predicted by this model will always be greater than or equal to the biomass loss predicted by the cumulative deforestation model. Assuming that degradation precedes deforestation, this model can be parameterized identically to the cumulative deforestation model but with a time shift element called a lag period. The parameterized model predicts functions as a baseline for the leakage area to predict the future degree of biomass loss due to deforestation and degradation at any point in time after the project start date, expressed as a proportion, had the project not been implemented.

Upon baseline reevaluation, the leakage model is updated to reflect the new cumulative deforestation model (see section 6.7). The lag period in the leakage model remains unchanged after baseline reevaluation.

10.3.1 Background

This background section contains general information about the model and the selected approach to fitting the model rather than specific methods used to build the leakage model.

$$F_{LE}(t, \eta, \delta_{LE}) = \frac{1}{1 + \exp[-\eta(t, \boldsymbol{\theta}) - \delta_{LE}]} \qquad [8]$$

The functional form of the leakage model defined by [8] is identical to the cumulative deforestation model, but adjusted for a lag period. The lag period is the length of time between when degradation starts and deforestation ultimately takes place. For example, a lag period of five years indicated that the forest is gradually degraded during a five-year period prior to it being deforested, on average. Figure 12 shows the relationship between degradation and deforestation for an arbitrary lag period.

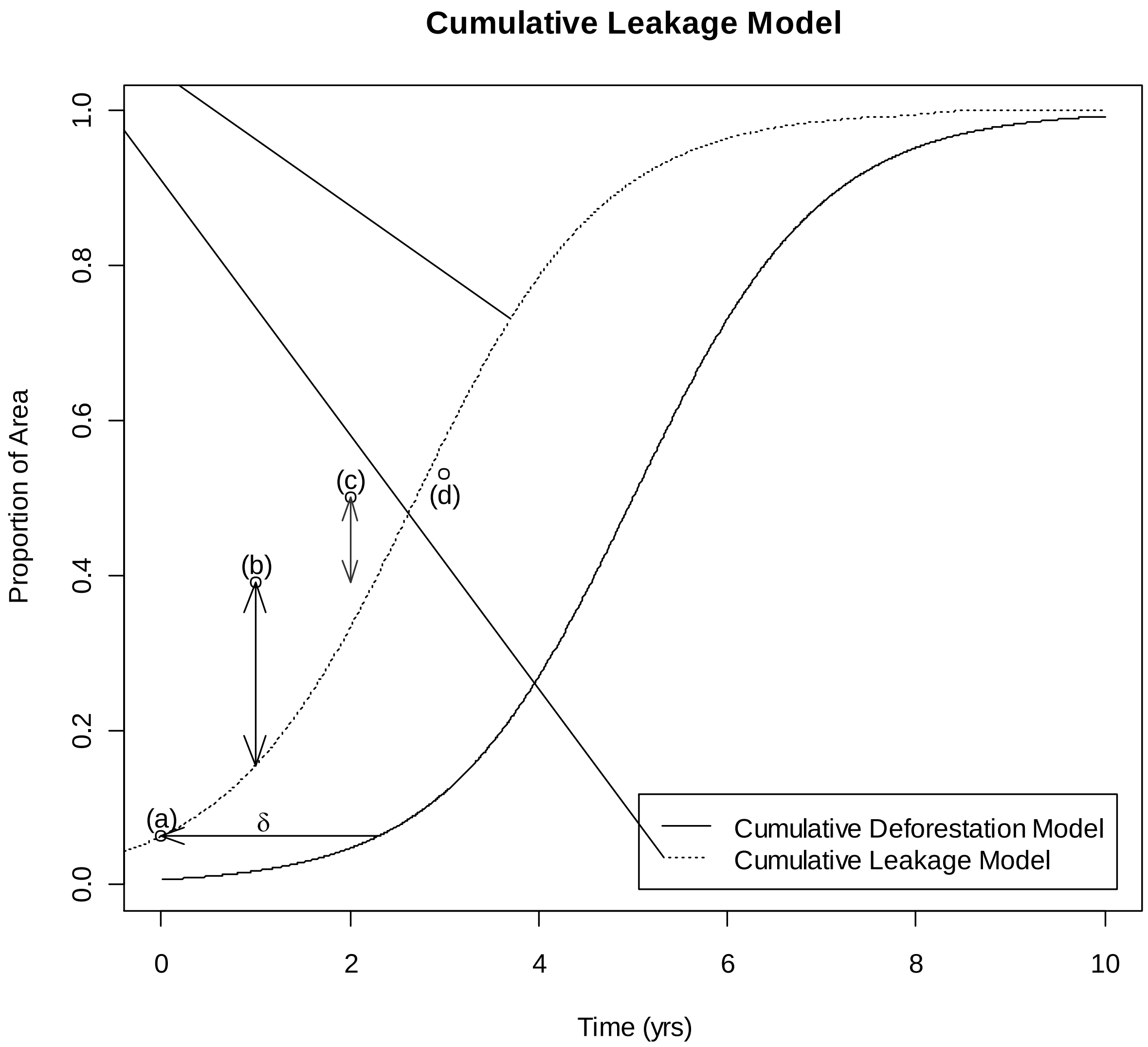

Figure 12: Graph of an example cumulative leakage model.
Cumulative leakage model showing combined degradation and deforestation (dashed) relative to cumulative deforestation (solid). Degradation occurs before deforestation. (a) The lag parameter, δ, is

estimated using equation [9] and a sample in the leakage area at the initiation of the project. In this example, δ = 2.2 years. (b) At the first monitoring period, the leakage factor is calculated as the difference between the cumulative leakage model and the results of the leakage sample. (c) At subsequent monitoring periods, the difference between the leakage sample at the current monitoring period and the greater of (i) the results of the leakage sample at the previous monitoring period and (ii) the prediction of the leakage model at the current monitoring period in order to avoid double counting of previously deducted cumulative deforestation/degradation. (d) If the results of the leakage sample lie below the cumulative leakage model, the leakage factor is zero. In examples (b) and (c), the leakage factor is given by the length of the arrows shown.

To fit the leakage model that is defined by [8] (with the same implicit form as [16]), the lag parameter δ_{LE} corresponding to the lag period must be estimated. To estimate the lag parameter, cumulative forest degradation and deforestation, d_t, is observed at the beginning of the project, t_0, in the leakage area. This proportion can be observed using a sample of plots in the leakage area.

$$\hat{\delta}_{LE} = \log(\hat{d}_t) + \log(1 - \hat{d}_t) + \hat{\alpha} + \hat{\boldsymbol{\theta}}\boldsymbol{x}^T \quad [9]$$

The lag period δ_{LE} is estimated as $\hat{\delta}_{LE}$ using [9] given the observed degradation and estimated cumulative deforestation at some point in time before the end of the first monitoring period assuming leakage has not occurred. Equation [9] is simply the inverse of the cumulative degradation model (called the logit function) which yields a time estimate, minus the time when degradation was observed. This estimate of the lag period is then applied to [8] to produce the parameterized leakage model that can be used to predict cumulative deforestation and degradation at any point in time.

If the lag period is estimated at a point in time after the project start date, then the assumption that leakage has not occurred up to this point in time must be confirmed as specified in section 10.3.3.

10.3.2 Sampling Degradation and Deforestation in the Leakage Area

The leakage area must be sampled prior to the end of the first monitoring period in order to estimate the lag period for the leakage model and at every subsequent monitoring period in order to estimate actual emissions due to leakage. Within the leakage area, randomly select a sample of point locations with uniform probability with a sample size $\hat{m}_{LE}$ determined by equation [10]. These point locations become the northeast corners of the fixed-area plots used to estimate degradation and deforestation in the leakage area permanently throughout the project lifetime. Select plot dimensions so that each plot area is at least two hectares. The dimensions of all plots should be the same. Visit these plots to observe the proportion degradation using the following ordinal scale. Record a factor (i.e. 0.2, 0.4, etc) corresponding to the observed above-ground biomass that is absent as evidenced by presence of stumps for each plot area:

Factor	Proportion of degradation
0.0	0%
0.2	0-20%
0.4	20-40%
0.6	40-60%
0.8	60-80% (severe degradation)
1.0	80-100% (including complete deforestation)

Neither the plot boundaries nor locations should be visibly marked on the ground, as they most likely exist in areas outside the project's control and visible marking may lead to preferential treatment of these plots. Rather, they should be monumented using a GPS.

These sample plots are observed each monitoring period to estimate leakage.

Uncertainty in measurement should be reduced as much as possible by developing a field protocol for sampling forest degradation. Training should be provided to collection teams.

PD Requirements: Sampling Deforestation and Degradation to Build the Leakage Model

The project description must include the following:

1. The sample size $\widehat{m}_{LE}$.
2. The dimensions of the sample plots.
3. A map of the leakage area showing the sample plot locations.
4. A table of plot data showing the observed factors.
5. A protocol for field sampling of degradation and deforestation.
6. Procedure for training of field collection teams.
7. Documentation of training for field collection teams.

10.3.3 Model Fitting

The leakage model is defined by [8] where δ_{LE} is the lag period. The lag period is estimated as $\hat{\delta}_{LE}$ using the proportion of cumulative degradation and deforestation in the leakage area at the beginning of the project $\hat{d}_0$ and the linear predictor $\hat{\eta}$ (see section 6.4.7) from the cumulative deforestation model using equation [9]. Once the lag period is estimated, then it can be applied to [8] to fit the leakage model. All other parameters of the leakage model are identical to those in the cumulative deforestation model. The leakage model is re-fit per the baseline at the end of each monitoring period.

If the lag period for the cumulative leakage model is estimated after the project start date but before the end of the first monitoring period, then each datum used to estimate the lag period must be a factor less than or equal to 0.8 to confirm that leakage has not occurred in the leakage area after the project start date. As defined, the leakage area is entirely forested at the project start date and therefore a factor greater than 0.8 indicates that leakage has probably occurred.

PD Requirements: Fitting the Leakage Model

The project description must include the following:

1. The estimated lag period $\hat{\delta}_{LE}$.

10.4 Estimating the Leakage Factor and Emissions from Leakage

At each monitoring period, sample the leakage area as detailed in section 10.3.2. The leakage factor is estimated as [33] where $o_i^{[m]}$ is the observed state of the i^{th} plot (a fraction from 0 to 1), $\mathcal{I}^{[m]}$ is the set of all observations made in the leakage area at monitoring period $[m]$, and $F_{LE}\left(t^{[m]}, \hat{\eta}^{[m]}, \hat{\delta}_{LE}\right)$ is the leakage model at time $t_2^{[m]}$ (the end time of the monitoring period) as defined by equation [8] at the end of the monitoring period.

The quantity of degradation and deforestation that may shift outside the project area cannot exceed what would have occurred in the project area, which is a reasonable assumption for the accounting of emissions from leakage. However, the size of the leakage area may exceed the size of the project area as defined in section 10.2. Therefore, equation [33] normalizes the estimated proportion of degradation and deforestation observed in the leakage area such that this proportion is comparable to that that would have occurred in the project area.

Depending on the relative value of the leakage predicted by the model and the results of the field-observed samples at the end of the current monitoring period, the leakage factor should be calculated in one of three ways. In the first monitoring period, the leakage factor is calculated as the difference between the mean of the field-observed leakage sample and the prediction of the leakage model as illustrated in example (b) below and in Figure 12. In subsequent monitoring periods, the leakage factor is calculated as the difference between the mean of the leakage sample and whichever is greater: the prediction of the leakage model or the results of the leakage sample at the previous monitoring period. This is necessary to avoid double counting when predicting deforestation and degradation based on a cumulative model, and is illustrated by example (c) below and in Figure 12. Any time the results of the field-observed leakage sample lies below the prediction of the leakage model, the leakage factor is zero (example (d) below and in Figure 12). From the leakage factor, quantify leakage emissions as equation [32].

To illustrate this process, consider the following fictitious example, illustrated in Figure 12.

Figure 12 (a): At the initiation of the project (t0), a sample of 100 plots is taken in the leakage area. The mean combined degradation and deforestation proportion in these plots is 0.063 (6.3%). 0.063 is plugged into equation [9] as d_t, and used to estimate the lag parameter, $\hat{\delta}_{LE}$. All other parameters in equation [9] as fitted for the cumulative deforestation model. In this example, $\hat{\delta}_{LE}$ = 2.2 years. This parameter is held constant until the baseline is reevaluated.

Figure 12 (b): To estimate leakage at each monitoring period, a new sample of the leakage area must be collected. In this example, at the end of the first monitoring period, the results of the sample in the leakage area give an estimated cumulative deforestation/degradation proportion in the leakage area of 0.39. The leakage model predicts that, under the baseline scenario, the cumulative deforestation and degradation proportion would be 0.16, so the leakage factor is estimated as 0.39 – 0.16 = 0.23.

Figure 12 (c): In the next monitoring period, the sample in the leakage area indicates that cumulative deforestation and degradation has increased to 0.50. The leakage model predicts that, under the baseline scenario, the cumulative deforestation and degradation proportion would be 0.33, so additional leakage has occurred in this monitoring period. However, the prediction of the model is less than the observed cumulative deforestation and degradation in the previous monitoring period. Only the difference between the results of the current sample and the results of the sample in the previous monitoring period is new during this monitoring period – the rest has already been accounted for. Consequently, the leakage factor is estimated as 0.50 – 0.39 = 0.11.

Figure 12 (d): By the third monitoring period, degradation and deforestation has slowed down, perhaps because project activities designed to mitigate leakage have been effective. The results of the leakage sample at the end of this monitoring period indicate that the combined deforestation and degradation in the leakage area is now 0.53. Degradation and deforestation has occurred since the last monitoring period, but only on a small portion of the leakage area. The leakage model predicts that, under the baseline scenario, the cumulative deforestation and degradation proportion would be 0.57, so the currently observed level of combined degradation and deforestation is less than that predicted under the baseline. The leakage factor for this monitoring period is zero.

PD Requirements: Estimating the Leakage Factor and Emissions From Leakage

The project description must include the following:

1. The estimated cumulative degradation and deforestation predicted by the leakage model, $F_{LE}\left(t^{[m]}, \hat{\eta}^{[m]}, \hat{\delta}_{LE}\right)$.
2. The estimated cumulative deforestation and a degradation in the leakage area, $\bar{o}^{[m]}$.
3. The leakage factor, $\hat{r}_{LE}^{[m]}$.
4. The estimated emissions from leakage, $C_{LE}^{[m]}$.

11 Quantification of Net GHG Emission Reductions and/or Removals

Net GHG Emission Reductions and Removals (NERs) for monitoring period $[m]$ are quantified as [34] where $C_{BE}^{[m]}$ is avoided baseline emissions, $C_{U}^{[m]}$ is the confidence deduction, $C_{PE}^{[m]}$ is the project emissions and $C_{LE}^{[m]}$ is emissions from leakage. The most recent version of the *VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination* must be applied to the quantified NERs for each monitoring period.

$$C^{[m]} = C_{BE}^{[m]} - C_{U}^{[m]} - C_{PE}^{[m]} - C_{LE}^{[m]} \qquad [34]$$

PD Requirements: Quantification of NERs

The project description must include the following:

1. Estimates for each component of the quantified NERs;
2. The total quantified NERs; and
3. The number of quantified NERs to be allocated to the buffer pool.

11.1 Determining Deductions for Uncertainty

The confidence deduction $C_{U}^{[m]}$ is determined as [35] where $U^{[m]}$ is the weighted quadratic average of the quantified uncertainty in the cumulative deforestation model, the soil carbon loss model and the carbon stock estimates [36].

PD Requirements: Confidence Deduction

The project description must include the following:

1. The weighted quadratic average of the quantified uncertainty in the cumulative deforestation model, soil carbon loss model and the carbon stock estimates as defined by [35].

11.2 Reversals from the Quantification of Negative NERs

In the event that the quantified NERs for any monitoring period are negative as a result of carbon stock losses, the project proponent must follow the VCS procedures for reversals as set out in the latest version of the VCS. If subsequent to baseline reevaluation per section 6.7, a new cumulative deforestation model falls below the old model (see Figure 11) this does not constitute a reversal. Rather if credits were generated from avoided deforestation prior to baseline reevaluation at a level greater than predicted by the new baseline model after baseline reevaluation, then the project proponent may not generate any new credits from avoided deforestation until the new cumulative deforestation model reaches the previous level of predicted deforestation that generated these credits.

At the end of the project crediting period, the project proponent must estimate the final level of cumulative deforestation using the most current baseline model and use this estimate to quantify the total number of cumulative credits per equation [34]. If this estimate is greater than the number of credits issued during the project crediting period, then this difference must be subtracted from the buffer pool.

11.3 *Ex-Ante* Estimation of NERs

Under the VCS, *ex-ante* estimates of the net carbon benefits of the project are only required to determine whether decreases in carbon pools or increases in GHG emissions are insignificant and need not be measured and monitored (VCS, 2010a). Additionally, e*x-ante* estimates of project benefits may be useful to project proponents for planning purposes. Use the project crediting period to estimate *ex-ante* project benefits,

The most significant factor in estimating project carbon benefits is likely to be an estimate of avoided baseline emissions which is derived from an estimate of carbon stocks and the baseline models. Estimates of *ex-ante* avoided baseline emissions can be made by assuming that the total carbon stock in the project area is equal to the initial carbon stock for each future monitoring period. This conservatively ignores growth of the existing forest, assuming that each carbon pool is at a steady state prior to project initiation. The projected avoided baseline emissions are estimated by applying the cumulative deforestation model and soil carbon loss model as described in sections 6.4.8 and 6.5.6 where monitoring period $[m]$ always indicates the initial carbon stock. If project activities include woody biomass burning or the sustainable production of charcoal, estimates of emissions due to these activities should be included in the *ex-ante* estimate of project benefits using the procedures in section 9. The project developer may assume that the demand for charcoal remains constant at a rate determined prior to project implementation. Since *ex-ante* data for leakage monitoring are unlikely to be available, *ex-ante* estimates of leakage should be estimated using expert knowledge and, if available, experience with past projects. For the purpose of assessing the significance of decreases in carbon pools or increases of emissions due to project activities, it is conservative to underestimate avoided baseline emissions and overestimate leakage and project emissions in *ex-ante* estimates of carbon benefits.

Using the assumptions outlined above, estimate the *ex-ante NERs* for each monitoring period $[m]$ as [34] where $C_{BE}^{[m]}$ is avoided baseline emissions, $C_{U}^{[m]}$ is the confidence deduction, $C_{PE}^{[m]}$ is the project emissions and $C_{LE}^{[m]}$ is emissions from leakage.

Reporting of *ex-ante* estimates is only required if the project proponent demonstrates that a carbon pool expected to increase in the baseline or a project emissions source is excluded from accounting under the *de minimus* rule.

PD Requirements: *Ex-Ante* Estimation of NERs

In the case when *ex-ante* estimates are used to prove the significance of emissions sources or estimate the quantity of NERs over the project crediting period, the project description must include the following:

1. The projected avoided baseline emissions, project emissions, and leakage for each monitoring period over the lifetime of the project.
2. A narrative description of sources used to estimate the leakage rate and demonstration that the estimated rate is conservative.
3. If included in project activities, a description of procedures used to estimate the rate of biomass burning and charcoal production and demonstration that these estimates are conservative.

12 Data and Parameters Not Monitored

See Appendix B, list of variables, for a complete list of all variables, data and parameters and a description of the frequency of monitoring for each.

13 Monitoring

13.1 Overview

The procedures described here provide a means of estimating the total carbon stock in selected pools within the project area and the uncertainty of that estimate at a given point in time. These procedures are used both for establishing the initial carbon stock within the project area and the carbon stock at each monitoring event $[m]$. This methodology employs fixed area plots coupled with allometric equations for estimating carbon stocks in large and small trees. Carbon stocks in dead wood are estimated using fixed area plots for the standing dead pool and line intersect sampling for the lying dead pool. Allometric equations or destructive sampling may be used for estimating non-tree carbon stocks. Soil carbon is estimated using soil samples collected from soil cores or pits. These sampling procedures are designed to detect both increases in carbon stocks, such as those that occur as a result of forest growth, and decreases in carbon stocks, such as changes that may take place as a result of degradation or natural disturbance events.

Carbon stocks must be estimated for the first monitoring period by sampling all plots in all strata. After the first monitoring period, all plots and all strata must be re-measured every five years, a process which may be accomplished on an intermittently rotating basis.

13.2 Stratification Guidelines

Stratification is recommended as a tool for minimizing sampling error. If two or more strata can be identified within the project area with similar carbon stocks and relatively small variance in relation to the variance of the total project area, stratification should reduce uncertainty in carbon stock estimation. The equations presented here assume stratification is used. However, if the project area is not stratified, the equations listed in this section are still applicable. In this case, all sums across strata include a single element. The standard error equations given in this methodology assume that stratum sizes are known exactly. To ensure this assumption is valid, strata should be delineated prior to sampling. Stratification may be revised at any monitoring period prior to subsequent forest re-measurement.

13.3 Sampling Guidelines

Sample plots are used to estimate carbon stocks in selected pools at a particular point in time. Changes in measured carbon stocks are used in conjunction with the baseline models to quantify the net GHG emissions or removals as a result of project activities. Changes on measured plots should reflect both changes due to natural processes such as growth and mortality, and changes due to human activity, such as management, harvest, or degradation. In order to avoid bias, plots should be marked inconspicuously, so that if degradation or management activities do occur in the project area, they apply uniformly to both areas within an established monitoring plot and areas outside of those plots.

13.3.1 Determining the Sample Size

Each stratum must contain at least two sample plots. In planning inventory activities, the project proponent may use the following guidelines for estimating sample size and allocating plots to strata. This step is not required, but may be useful in planning an inventory of carbon stocks that minimizes expenditures required to achieve a specified precision level. Three methods can be used to estimate the number of plots and allocation of those plots to strata that will maximize sampling efficiency, based on the amount of information available prior to sampling. A pilot sample may be conducted to initially estimate the mean and standard deviation of carbon stocks in each stratum before making use of these guidelines. For more information on how to determine the size of a pilot sample see Avery and Burkhart (Avery & Burkhart, 2002).

Proportional Allocation

If the only information available is the area of each stratum as delineated on a GIS, proportional allocation can be used. Determine the total estimated sample size $\hat{n}_{total}$ using equation [37], then determine the number of plots $\hat{n}_k$ in each stratum k using equation [38].

Neyman Allocation

If the area of each stratum as well as an estimate of the population variance of each stratum is available, Neyman allocation can be used. First determine the proportion of plots, w_k, that will fall in each stratum using equation [39]. Estimate the total sample size $\hat{n}_{total}$ using equation [41], then estimate the number of plots $\hat{n}_k$ in each stratum k using equation [42] where $\hat{\sigma}_k^2$ can be estimated from a pilot sample using equation [46].

Optimal Allocation

If the area, an estimate of variance, and an estimate of the relative cost of sampling is available for each stratum, optimal allocation can be used. First determine the proportion of plots, w_k, that will fall in each stratum using equation [40]. Estimate the total sample size $\hat{n}_{total}$ using equation [41], then estimate the number of plots $\hat{n}_k$ in each stratum k using equation [42] where $\hat{\sigma}_k^2$ can be estimated from a pilot sample using equation [46].

13.3.2 Guidelines for Determining Plot Size

The optimum plot size in a carbon inventory is a function of the variability in carbon stocks inherent in the population and measurement costs. In general, as plot size increases, the variance in carbon stocks across plots within a population decreases. Aside from stratification, inventory precision can be improved by either increasing either the size or number of plots measured. Plot size should be chosen by the project proponent based on experience with similar forest types, reviews of technical literature, and, optionally, a pilot sample. If a pilot sample is used, plots can optionally be installed using the largest plot radius under consideration and measurements of distance from plot center to each tree recorded. This allows for the synthetic construction of plots of smaller size. The required sample size to obtain the targeted precision level for each plot radius under consideration can then be computed using the appropriate equations described above. If a pilot sample is not feasible or desired, the between plot variance of a new plot size can be estimated from the between plot variance of a known plot size using equation [43]. It should be noted that many project proponents perform "feasibility studies" in a potential project area; this presents an optimal opportunity to establish and measure a pilot sample.

Project proponents use different sized plots for different carbon pools. For example, project proponents may choose to use a nested plot design in which small trees are measured on a plot of smaller radius than radius of the plot for large trees. Small trees are differentiated from large trees based on the *size class diameter*.

13.3.3 Systematic vs. Random Sampling

Project proponents may choose to carry out their inventory using either a random or a systematic (grid-based) sample within each stratum. Systematic sampling helps ensure uniform coverage of the area sampled and can be cost efficient, but risks bias if the sampling units coincide with periodicity in the population. Further, estimating the sampling error based on a systematic sample is difficult. This methodology allows for the use of systematic sampling with the following guidelines:

- Project proponents must identify any periodic variation potentially present in the project area due to topography, management history, or other factors and document how the sampling design avoids bias that may result from these periodicities.
- If line-plot cruises or other linearly based methods are used, effort should be made to make cruise lines run perpendicular to slopes, rather than along contours, whenever possible.
- Systematic samples should employ a randomized start point.

The same procedures are applied to estimate the sampling error for both methods.

13.4 Estimating Total Carbon Stocks

Estimate carbon stocks for selected carbon pools using the strata $\mathcal{S}$, plots within each stratum $\mathcal{P}_k$ and measurements within each plot $\mathcal{X}_{k,j}$ where each measurement is $x_{i,j,k}$. For example, a measurement might apply to a soil sample or a prediction of biomass from an allometric equation.

Estimate the total carbon stock $C_{TOTAL}^{[m]}$ for the project area using equation [62] where $\mathcal{C}$ is the set of all required and selected optional carbon pools. $C_{TOTAL}^{[m]}$ is also used in the calculation of uncertainty.

13.5 Estimating Carbon in Above-ground Biomass

Carbon stocks in live trees are estimated by measuring diameter at breast height and, if required by the selected allometric equation, height of trees within sample plots. Allometric equations should be chosen or developed based on the guidance in section 13.13. It is very important to use or develop good allometric equations. Good practice guidance for developing new allometric equations can be found in Parresol (1999). To ensure a consistent inventory across monitoring periods, the project proponent should clearly document tree measurement procedures, including rules for including or excluding trees that fall on the edge of a plot and rules for measuring trees that lean, have irregular stems, buttresses, or stilt roots. Project proponents may elect to use different plot sizes for measurement of small and large trees to improve inventory efficiency. The minimum diameter appropriate for measuring trees with this method should be informed by the identified size class diameter.

13.5.1 Estimating Carbon in Above-ground Large Trees

1. Estimate the carbon stock per unit area in each plot, $y_{j,k}$, as equation [45] where $x_{i,j,k}$ is the predicted carbon stock for the i^{th} large tree in plot j, stratum k as given by equation [50].

2. Use $y_{j,k}$ to calculate the total carbon stock $C_{AGLT}^{[m]}$ in above-ground large trees as equation [44] and standard error $\hat{\sigma}_{SE,AGLT}^{[m]}$ of the carbon stock in above-ground large trees as equation [47] where $\hat{\sigma}_k^2$ is equation [46].

13.5.2 Estimating Carbon in Above-ground Small Trees

1. Estimate the carbon stock per unit area in each plot, $y_{j,k}$, as equation [45] where $x_{i,j,k}$ is the predicted carbon stockfor the i^{th} small tree in plot j, stratum k as given by equation [50].

2. Use $y_{j,k}$ to calculate the total carbon stock $C_{AGST}^{[m]}$ in above-ground small trees as equation [44] and standard error $\hat{\sigma}_{SE,AGST}^{[m]}$ of the carbon stock in above-ground large trees as equation [47] where $\hat{\sigma}_k^2$ is equation [46].

13.5.3 Estimating Carbon in Above-ground Non-trees

Non-tree woody biomass includes woody shrubs and any trees smaller than the minimum diameter appropriate for using the methods described for tree biomass. Non-tree biomass can be estimated using either destructive sampling in a clipped plot, allometric equations, or a combination of the two approaches. Clip plots are appropriate for annual plants and small shrubs. Allometric equations are appropriate for perennials and large shrubs. If both methods are used simultaneously, clear rules must be established to ensure no double counting of non-tree biomass occurs. In this case $C_{AGNT}^{[m]}$ is estimated using the sum of the estimators described below and $\hat{\sigma}_{SE,AGNT}^{[m]}$is estimated using equation [63] with the estimators described for each method. Non-tree biomass, or a subset of species in the non-tree biomass pool, may be conservatively excluded from project accounting. The plot size used for non-tree biomass may differ from the plot size used for other carbon pools.

Destructive Sampling Method

In this method, above-ground biomass is estimated by harvesting the biomass in a plot of known area, drying and weighing the harvested sample, and calculating the mass per unit area. Alternatively, wet mass may be measured on each plot and empirically adjusted to compensate for moisture content. These plots constitute separate measurement units from the plots used for tree biomass estimation, though they may exist inside the tree plot. The area of the clipped plot will typically be much smaller than the area of tree biomass plots and may be selected by the project proponent. Large plots allow for more precision in the estimation of carbon stocks, but require more effort to sample. If permanent plots are used, the location of the clip plot within the larger tree plot should not be the same during each measurement period to avoid bias that may result from clipping the same area during each measurement period, as repeated clipping may impact the productivity of the site. If the plot happens to fall in a location with little to no non-tree biomass (for example, because a large tree occupies most of the plot area), the plot should not be moved. In the field, a sampling frame can be placed over the ground to accurately determine the area to be clipped. All vegetation originating within this frame should be clipped to a consistent height above the ground, preferably as near to ground level as is feasible. Each sample should then be dried and weighed.

1. Estimate the carbon stock per unit area in each plot, $y_{j,k}$, as equation [44] where $y_{j,k}$ is equation [53] and $m_{dry,j,k}$ is the dry mass of biomass clipped on plot j in stratum k. If drying and weighing each harvested sample is not feasible, a well-mixed subsample may be dried and weighed and $m_{dry,j,k}$ calculated from the wet mass using equation [55].

2. Use $y_{j,k}$ to estimate the total carbon stock $C_{AGNT}^{[m]}$ in above-ground non-tree biomass as equation [44] and standard error $\hat{\sigma}_{SE,ABNT}^{[m]}$ of the carbon stock in above-ground non-trees as equation [47] where $\hat{\sigma}_k^2$ is equation [46].

Allometric Equation Method

Allometric equations can be applied to estimate the above-ground biomass of non-trees. These equations might be size-class or species-specific.

1. Estimate the carbon stock per unit area in each plot, $y_{j,k}$, as equation [45] where $x_{i,j,k}$ is equation [54] for the i^{th} shrub in plot j, stratum k.
2. Use $y_{j,k}$ to estimate the total carbon stock $C_{AGNT}^{[m]}$ in above-ground non-tree biomass as equation [44] and standard error $\hat{\sigma}_{SE,AGNT}^{[m]}$ of the carbon stock in above-ground non-trees as equation [47] where $\hat{\sigma}_k^2$ is equation [46].

13.6 Estimating Carbon in Below-ground Biomass

Below-ground biomass is estimated by applying a root to shoot ratio to the above-ground biomass estimate for the above-ground large tree, above-ground small tree, and above-ground non-tree carbon pools.

13.6.1 Estimating Carbon in Below-ground Large Trees

1. Estimate the carbon stock per unit area in each plot, $y_{j,k}$, as equation [45] where $x_{i,j,k}$ is the product of r_{sp}, the root to shoot ratio for species sp and equation [50] for the i^{th} large tree in plot j, stratum k.
2. Use $y_{j,k}$ to calculate the total carbon stock $C_{BGLT}^{[m]}$ in below-ground large trees as equation [44] and standard error $\hat{\sigma}_{SE,BGLT}^{[m]}$ of the carbon stock in below-ground large trees as equation [47] where $\hat{\sigma}_k^2$ is equation [46].

13.6.2 Estimating Carbon in Below-ground Small Trees

1. Estimate the carbon stock per unit area in each plot, $y_{j,k}$, as equation [45] where $x_{i,j,k}$ is the product of r_{sp}, the root to shoot ratio for species sp and equation [50] for the i^{th} small tree in plot j, stratum k.
2. Use $y_{j,k}$ to calculate the total carbon stock $C_{BGST}^{[m]}$ in below-ground small trees as equation [44] and standard error $\hat{\sigma}_{SE,BGST}^{[m]}$ of the carbon stock in below-ground small trees as equation [47] where $\hat{\sigma}_k^2$ is equation [46].

13.6.3 Estimating Carbon in Below-ground Non-trees

1. Estimate the total carbon stock $C_{BGNT}^{[m]}$ in below-ground non-tree biomass as [64].
2. Estimate the standard error of total carbon stock $\hat{\sigma}_{SE,BGNT}^{[m]}$ as equation [65].

13.7 Estimating Carbon in Standing Dead Wood

Standing dead trees shall be measured using the same procedures developed for measuring standing live trees. Standing dead trees shall be categorized into two decomposition classes:

- Trees with branches and twigs that resemble live trees (except for leaves) (Class I)
- Trees that show loss of twigs, branches or bole mass (Class II)

To estimate the total carbon stock in the standing dead pool:

1. Estimate the carbon stock per unit area in each plot,$y_{j,k}$, as equation[66] where$y_{INTACT,j,k}$ and $y_{DECAYED,j,k}$ are computed as described below.

2. Use $y_{j,k}$ to calculate the total carbon stock $C_{SDW}^{[m]}$ in standing dead wood as equation [44].

3. Calculate the standard error $\hat{\sigma}_{SE,SDW}^{[m]}$of the carbon stock in standing dead wood as equation [47] where $\hat{\sigma}_k^2$ is equation [46].

Decay Class I

The carbon stock of standing dead trees in decay class I is estimated using the same equations developed for live trees. Estimate the carbon stock for each plot $y_{INTACT,j,k}$ as equation [45] where $x_{i,j,k}$ is equation [50] for the i^{th} treein plot j, stratum k.

Decay Class II

The carbon stock of standing trees in decay class II is conservatively estimated as the biomass in only the remaining bole. DBH and height should be measured on each tree in decomposition class 2. The diameter at the top of the stem can be measured using a relascope or similar instrument, or it can be conservatively assumed to be zero. The volume of each dead tree is then estimated as the frustum of a cone. Estimate the carbon stock for each plot $y_{DECAYED,j,k}$ as equation [45] where $x_{i,j,k}$ is equation [51] for the i^{th} treein plot j, stratum k and $v_{i,j,k}$ is equation [52].

13.8 Estimating Carbon in Lying Dead Wood

Lying dead wood is sampled using the line intersect method. At each plot, establish two transects of at least 50m length through the plot center. The first transect should be oriented at a random angle, while the second transect should be oriented perpendicularly to the first transect. Record the diameter and density class of each piece of lying dead wood that intersects the vertical plane established by each transect. The diameter should be measured at the point of intersection. If a piece of lying dead wood is forked and intersects the transect at more than one point, each point of intersection should be recorded separately. The minimum measurement diameter may be established on a project-specific basis, but should be documented and held constant across all measurement periods. Each piece of measured wood should be classified as sound, intermediate or rotten using the machete test as recommended by the IPCC Good Practice Guidance for Land-Use, Land Use Change and Forestry (4.3.3.5.3) (IPCC, 2003). The mean density of dead wood, $\bar{\rho}_d$, in each decay class d, must be estimated as the mean of a sample of discs cut from down logs within the project area. Each disc should be dried and density estimated as dry mass over volume. The sample should be large enough to achieve a standard error of the mean within +/- 15% at a 95% confidence level.

1. Estimate the total carbon stock $y_{j,k}$, per unit area for stratum k transect j as equation [58] where $x_{i,j,k,d}$ is the diameter of the i^{th} piece of lying dead wood equation in density class d, transect j, stratum k.
2. From $y_{j,k}$, estimate y_k, the total carbon stock in lying dead wood in stratum k as equation [56].
3. From $y_{j,k}$, estimate the variance of carbon in lying dead wood in stratum k,$\hat{\sigma}_k^2$, as equation [57].
4. Estimate the total stock $C_{LDW}^{[m]}$ in lying dead wood as equation [59].
5. Estimate the standard error of the carbon stock in lying dead wood $\hat{\sigma}_{SE,LDW}^{[m]}$ as equation [48].

The estimation of Carbon in lying dead wood may be conservatively omitted at the discretion of the project proponent.

13.9 Estimating Carbon in Soil

The soil carbon pool is estimated from soil samples taken in sample plots. Samples may be taken using a soil core or by digging a soil pit. Because of the high degree of variability in soil carbon stocks, it is recommended that several samples be taken from different randomly selected locations *within each plot* (IPCC, 2003). At each sample location, multiple horizons or depth increments should be extracted (at least 3 are recommended) to ensure that the soil is being measured to a sufficient spatial resolution along its depth. Depth increment of each sample taken must be recorded . Bulk density and carbon concentration should be measured separately by soil horizon or depth increment, as it is important to apply these individual measurements to achieve mass-equivalent measurement. Bulk density and carbon concentration should be evaluated by a laboratory that follows internationally recognized standards (e.g. FAO standards) to minimize errors and bias. If multiple samples within a plot are bulked (i.e. combined) in the field they must be bulked by horizon or depth increment and mixed thoroughly before extracting subsamples for the lab analyses. This mixing can be done prior to laboratory measurement, or samples from different depths can be analyzed separately and a weighted average with weights proportional to sample increment depth can be used to compute the mean soil carbon stock for the entire depth profile sampled. In soils with coarse fragments (> 2mm), both density and carbon concentration should be based on the fine fraction of the soil (< 2 mm), corrected for coarse fragments. A minimum depth for soil sampling should be established and this minimum depth should be no less than the depth to which soil is disturbed during farming, typically a minimum 30cm. Care should be taken to synthesize the soil measurements made within the project area with those made in the reference area (see section 6.5.3 ‘Sampling Soil Carbon Loss’). To ensure comparisons made between project area samples and reference area samples are consistent, collection must be done to allow calculation of soil carbon stocks on a *mass-equivalent* basis, per (Ellert, Janzen & Entz, 2002; Ellert & Bettany, 1995).

The guidance provided in section 4.3.3.5.4 of the GPG-LULUCF (IPCC, 2003) must be adhered to when choosing laboratory methods for analyzing soil carbon content.

1. Calculate the corrected bulk density for each plot using equation [60].
2. Estimate the soil carbon stock per unit area, $y_{j,k}$, for plot j, stratum k using equation [61].
3. Estimate the total stock $C_{SOIL}^{[m]}$ as [44].

4. Estimate the variance within each stratum as equation [46].
5. Estimate the standard error of the total carbon stock in soil carbon, $\hat{\sigma}_{SE,SOIL}^{[m]}$, as equation [49].

13.10 Estimating Carbon in Wood Products

It is conservative to omit long-lived wood products from the project scenario. See section 8.10 for the estimation of wood products under the baseline scenario.

13.11 Uncertainty

To ensure that carbon stocks are estimated in a way that is accurate, verifiable, transparent, and consistent across measurement periods, the project proponent must establish and document clear standard operating procedures and procedures for ensuring data quality. At a minimum, these procedures must include:

- Comprehensive documentation of all field measurements carried out in the project area. This document must be detailed enough to allow replication of sampling in the event of staff turnover between monitoring periods.
- Training procedures for all persons involved in field measurement or data analysis. The scope and date of all training must be documented.
- A protocol for assessing the accuracy of plot measurements using a check cruise and a plan for correcting the inventory if errors are discovered.
- Protocols for assessing data for outliers, transcription errors, and consistency across measurement periods.
- Data sheets must be safely archived for the life of the project. Data stored in electronic formats must be backed up.

13.12 Estimating Uncertainty in Total Carbon Stocks

Estimate the standard error of the total carbon stock for the project area, $\hat{\sigma}_{SE,TOTAL}^{[m]}$ by combining the standard errors of the required and selected optional pools using equation [63]. Calculate the percent uncertainty in the total carbon stock $U_{TOTAL}^{[m]}$ as equation [67].

13.13 Guidelines for Using Allometric Equations

When available, allometric equations from existing IPCC, government, or peer reviewed literature may be used. Equations should be derived from trees of a wide range of diameters and, if included, heights and should not be used beyond the size range for which they were developed. When equations are selected from literature, justification should be provided for their applicability to the project area considering climatic, edaphic, geographical and taxonomic similarities between the project location and the location in which the equation was derived. When possible, species-specific equations should be used. If generalized equations developed for wide scale application are used, they must be validated using the procedures below.

When equations are taken from existing literature that is not similar to the project area as described above or are selected from a biome-wide database, such as those provided Tables 4.A.1 to 4.A.3 of the GPG-LULUCF (IPCC, 2003), they must be verified by destructively harvesting, within the project area but outside the sample plots, a minimum of 5 trees of different sizes. The harvested trees must be weighed and their biomass and compared to the selected equation. If the biomass estimated from all harvested trees is within +/- 10% of that predicted by the equation, then the selected equation is considered suitable for the project.

13.13.1 Developing Allometric Equations

Allometric Equations for Trees

If allometric equations are developed for the project area, the guidance provided by Parresol (1999) should be used to fit appropriate statistical models. New models must be validated using leave-one-out cross validation as follows:

Assume a model of the form $y = f(\boldsymbol{x})$, where y is measured biomass and $\boldsymbol{x}$ is a vector of regressors.

1. Temporarily remove observation $\left(y_{i,}\boldsymbol{x}_i\right)$ from the dataset used to fit the model.
2. Refit the model, f_{-i} , with the remaining data points and use it to estimate $\hat{y}_i$, the predicted biomass at the point that was removed from the dataset prior to model fitting as given by equation [68].
3. Estimate the cross-validated error for this data point, $\hat{e}_i$, expressed as a proportion of the true biomass using equation [69] .
4. Repeat 1-3 for each observation.
5. Calculate the mean cross-validated error $\bar{E}$ as equation [70], where $\mathcal{X}$ is the set of all observations used in model fitting.

The developed equation is considered valid if $\bar{E} < 15\%$.

Allometric Equations for Non-Trees

Allometric equations for shrubs can be developed by harvesting a representative sample from the project area, drying and weighing the sample, and relating the sampled biomass to variables easily measured in the field. The independent variables that are suitable for predicting shrub biomass may vary across environments and vegetation types and may include but are not limited to number of stems, stem diameter, height, size class, crown diameter, and percent cover. In some situations, developing a continuous equation that represents shrub mass as a function of one or more of the above variables is not practical. In this case, a simple average of the biomass of the sample collected per stem or per plant can be used instead. Where appropriate to project vegetation types, separate averages for different size classes and species of shrubs should be used.

13.14 Reporting Requirements

PD Requirements: Monitoring of Carbon Stocks in the Project Area

The project description must include the following for each monitoring period:

1. Summary of sampling procedures, with a copy of detailed sampling methods included as an appendix.
2. Documentation of training provided to field crews.
3. Documentation of data quality assessment such as the results from a check cruise.
4. Map showing strata boundaries and plot locations.
5. List of plot coordinates.
6. Description of the plot size and plot layout used for each carbon pool.
7. Documentation of the source of all parameters and allometric equations.
8. If allometric equations are developed, a detailed description of the development process including model fitting and selection.
9. The estimated total carbon stock, standard error of the total, and sample size for each stratum and selected carbon pool in the project area.
10. The estimated total carbon stock and standard error of the total for the entire project area.

14 Data and Parameters Monitored

See Appendix B, list of variables, for a complete list of all variables, data and parameters and a description of the frequency of monitoring for each.

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Appendix A: Equations

$$o_i = \begin{cases} 1\ if\ deforested\ at\ (t_i, x_i, y_i) \\ 0\ if\ forested\ at\ (t_i, x_i, y_i) \end{cases}$$		[1]
Variables	o_i= forest state at a given point in space-time t_i= the time of the i^{th} sample point x_i= the latitude of the i^{th} sample point y_i= the longitude of the i^{th} sample point	
Section References	6.4.1, 6.4.3	
Comments	Observation of forest state at a given point in space and time.	

$$P(t_i, x_i, y_i) = P(x_i, y_i \mid t_i) P(t_i)$$		[2]
Variables	$P(t_i, x_i, y_i)$= probability of observation in a point in space and time t_i= the time of the i^{th} sample point x_i= the latitude of the i^{th} sample point y_i= the longitude of the i^{th} sample point	
Section References	6.4.1	
Comments	Probability of observing any one sample point in space and time.	

$$P(x_i, y_i \mid t_i) = \frac{\#(observations\ at\ x_i, y_i) \times \#(observations\ at\ t_i)}{\#(historic\ images) \times \#(total\ observations)}$$		[3]
Variables	$P(t_i, x_i, y_i)$= probability of observation in a point in space and time t_i= the time of the i^{th} sample point x_i= the latitude of the i^{th} sample point y_i= the longitude of the i^{th} sample point	
Section References	6.4.1	
Comments	The conditional probability of observing a sample point in space given time.	

$$P(t_i) = \frac{1}{\#(historic\ images)}$$		[4]
Variable	$P(t_i)$ = probability of observing any sample point in time	
Section References	6.4.1	
Comments	The probability of observing any sample point in time with a given number of historical images	

$$w_i \propto \frac{1}{\#(observations\ at\ x_i, y_i) \times \#(observations\ at\ t_i)}$$		[5]
Variable	w_i = the weight applied to the i^{th} sample point t_i = the time of the i^{th} sample point x_i= the latitude of the i^{th} sample point y_i= the longitude of the i^{th} sample point	
Section References	6.4.1, 6.4.3	
Comments	Observation weight of observations of forest state, proportional to the inverse of the probability of observing any one particular sample point	

$$\hat{m}_{DF} \geq \frac{1}{2}\left(\frac{\hat{\sigma}_{DF}1.96}{0.01}\right)^2$$	[6]
Variables	$\hat{m}_{DF}$= the estimated sample size in the space of the reference area given the pilot sample data $\hat{\sigma}_{DF}$= a Horvitz-Thompson estimate of the standard deviation of deforestation state
Section References	6.4.3
Comments	The minimum sample size $\hat{m}_{DF}$ in the space of the reference area required for fitting the deforestation model. Based on a normal approximation and rewritten from an approximate confidence interval at 95% with threshold of +/- 1% of the estimated mean. +/- 15% of the mean cannot be used as the threshold because of problems associated with peak variance. The ½ factor is used because we assume at least double-coverage so we divide the approximated sample size by 2 to get the sample size in the reference area. $\hat{m}_{DF}$ has an upper bound of 4802, the maximum sample size. (Lohr, 2009)

$$\eta = \alpha + \beta t + \boldsymbol{\theta}\boldsymbol{x}^T$$	[7]
Variables	η= linear predictor given time and deforestation covariates α= Intercept of linear predictor of cumulative deforestation model β= time parameter of linear predictor of cumulative deforestation model $\boldsymbol{\theta}$ = parameter vector of cumulative deforestation model $\boldsymbol{x}$ = vector of observed covariates to deforestation t = time
Section References	6.4.7, 6.4.8
Comments	Linear predictor of deforestation, part of the logistic deforestation model (A. C. Davidson, 2003; Freedman, 2009)

$$F_{LE}(t,\eta,\delta_{LE}) = \frac{1}{1+\exp[-\eta(t,\boldsymbol{\theta})-\delta_{LE}]}$$	[8]
Variables	$F_{LE}(t,\eta,\delta_{LE})$ = leakage model η = linear predictor given time and deforestation covariates t = vector of observed times to forest state. θ = parameter vector of cumulative deforestation model δ_{LE} = lag parameter of leakage model.
Section References	10.3.3
Comments	Leakage model

$$\hat{\delta}_{LE} = \log(\hat{d}_t) + \log(1-\hat{d}_t) + \hat{\alpha} + \widehat{\boldsymbol{\theta}}\boldsymbol{x}^T$$	[9]
Variables	δ_{LE} = lag parameter of leakage model $\hat{d}_t$= estimate of cumulative deforestation and degradation $\hat{\alpha}$ = estimated intercept of linear predictor of cumulative deforestation model $\widehat{\boldsymbol{\theta}}$ = estimated parameter vector of cumulative deforestation model $\hat{\beta}$ = estimated time parameter of linear predictor of cumulative deforestation model $\boldsymbol{x}$ = vector of observed covariates to deforestation
Section References	10.3.3
Comments	Estimator of lag parameter in leakage model. This equation is based on the estimated linear predictor of the cumulative deforestation model $$\hat{\eta} = \hat{\alpha} + \hat{\beta}t + \widehat{\boldsymbol{\theta}}\boldsymbol{x}^T.$$

$$\hat{m}_{LE} \geq \left(\frac{\hat{\sigma}_{DF}1.96}{0.1}\right)^2$$	[10]
Variables	$\hat{m}_{LE}$ = the estimated minimum sample size in the leakage area. $\hat{\sigma}_{DF}$ = the estimated standard deviation of the state observations used to fit the cumulative deforestation model
Section References	6.4.3
Comments	The estimated sample size in the leakage area. Based on a normal approximation and rewritten from an approximate confidence interval at 95% with threshold of +/- 10% of the estimated mean. $\hat{m}_{FD}$ has an upper bound of 98, the maximum sample size. For a small estimated deforestation rate, a larger sample than estimated is recommended. (Lohr, 2009)

$$G(t,\lambda) = \int_0^\infty \lambda \exp(-\lambda t)\, dt = 1 - \exp(-\lambda t)$$	[11]
Variables	$G(t,\lambda)$ = proportion of soil carbon lost at time t with mean rate λ λ = exponential soil carbon decay parameter t = time
Section References	6.5.1, 6.5.6
Comments	Soil carbon loss model.

$$\hat{\ell}_{max} = \sum_{s \in \mathcal{S}} w_s \left[1 - \left(\frac{a_{project}}{C_{SOIL}^{[0]}}\right)\left(\frac{1}{n}\sum_{i \in \mathrm{n}} y_i\right)\right]_s$$		[12]
Variables	$\hat{\ell}_{max}$= the estimated maximum proportion of soil carbon lost over time $C_{SOIL}^{[0]}$= the estimated carbon stock in soil carbon *within the project area* at monitoring period $[0]$ y_i = the soil carbon stock of the i^{th} measurement in the reference area (in tonnes per unit area) n = total number of samples in strata s $a_{project}$ = total project area $\mathcal{A}$ = the set of all sampled farms in the reference area used to estimate the maximum proportion of carbon loss s= individual strata $\mathcal{S}$ = set of all strata in the project area w_s = Normalized strata weight: (area of strata s / $a_{project}$), all weights sum to 1.	
Section References	6.5.1, 6.5.5 Model Fitting	
Comments	Long term equilibrium value of soil proportion after carbon loss.	

$$\ell_{max} G(t,\lambda) = \ell_{max} \int_0^{\infty} \lambda \exp(-\lambda t)\, dt = \ell_{max}[1 - \exp(-\lambda t)]$$		[13]
Variables	ℓ_{max} = the estimated maximum proportion of soil carbon lost over time $G(t,\lambda)$ = proportion of soil carbon lost at time t with mean rate λ λ = mean rate of soil carbon loss t = time	
Section References	6.5.1	
Comments	This is an adaptation of [11] to include a maximum soil carbon loss proportion.	

$S(t_1, t_2, \lambda, \ell_{max}) = \ell_{max}[G(t_2, \lambda) - G(t_1, \lambda)]$	[14]
Variables	$G(t, \lambda)$ = proportion of soil carbon lost at time t with mean rate λ S = soil carbon loss model t_i = the time of the i^{th} sample point ℓ_{max}= the maximum proportion of soil carbon lost over time λ = the mean rate of soil carbon loss
Section References	6.5.1
Comments	Equivalency

$U_{DF} = \frac{1.96\hat{\sigma}_{DF}}{\sqrt{n_{DF}} \times \sum_{i \in \mathcal{J}} w_i o_i}$	[15]
Variables	U_{DF} = estimated uncertainty in the cumulative deforestation model $\hat{\sigma}_{DF}$ = a Horvitz-Thompson estimate of the standard deviation of deforestation state n_{DF} = the total number of state observations made to fit the cumulative deforestation model w_i = the weight applied to the i^{th} sample point o_i = state observation for the i^{th} sample point $\mathcal{J}$ = the set of all observations of deforestation.
Section References	6.4.9
Comments	An approximate estimate of uncertainty at the 95% confidence level for the cumulative deforestation model, assuming a normal approximation. This is derived as the standard error of the estimate at the 95% confidence level divided by the estimated mean deforestation rate. (Lohr, 2009)

$$F_{DF}(t,\eta) = \frac{1}{1+\exp[-\eta(t,\boldsymbol{\theta})]}$$	[16]
Variables	F_{DF} = proportion of cumulative deforestation η = linear predictor given time and deforestation covariates; [7] t = time $\boldsymbol{\theta}$ = parameter vector of the cumulative deforestation model
Section References	6.5.1,6.4.7, 6.4.8, 10.4
Comments	Logistic model of cumulative deforestation bounded by a reference or project area. (Arellano-Neri & Frohn, 2001; Kaimowitz, Mendez, Puntodewo, & Vanclay, 2002; Linkie, Smith, & Leader-Williams, 2004; Ludeke, Maggio, & Reid, 1990; Mahapatra & Kant, 2005)

$$\hat{\sigma}_{DF} = \sqrt{\left[\sum_{i\in\mathcal{J}} w_i o_i\right]\left[1-\sum_{i\in\mathcal{J}} w_i o_i\right]}$$	[17]
Variables	$\hat{\sigma}_{DF}$= a Horvitz-Thompson estimate of the standard deviation of deforestation state w_i = the weight applied to the i^{th} sample point o_i= state observation for the i^{th} sample point $\mathcal{J}$= the set of all observations of deforestation.
Section References	6.4.3, 6.4.9
Comments	This is the standard deviation of observed deforestation and derives from an estimate of variance for a Bernoulli random variable.(Lohr, 2009)

$$S(t_1,t_2,\lambda,\ell_{max}) = \ell_{max}[\exp(-\lambda t_1) - \exp(-\lambda t_2)]$$	[18]
Variables	S = soil carbon loss model t_i = the time of the i^{th} sample point ℓ_{max} = the maximum proportion of soil carbon lost over time λ = mean rate of soil carbon loss
Section References	6.5.1,6.5.5, 6.5.6
Comments	Soil carbon loss model

$U_{SCL} = 1.96 \times \hat{\sigma}_{SCL} \times \left[\sqrt{n_{SCL}} \times \frac{1}{n_{SCL}} \sum_{i \in \mathcal{A}} y_i \right]^{-1}$		[19]
Variables	U_{SCL}= estimated uncertainty of the soil carbon loss model $\hat{\sigma}_{SCL}$= the estimated standard deviation of soil carbon stocks in the reference area n_{SCL}= the actual sample size used to estimate the maximum soil carbon loss proportion in the reference area, equal to $\#(\mathcal{A})$ y_i = the soil carbon stock of the i^{th} measurement in the reference area (in tonnes per unit area) $a_{project}$ = total project area $\mathcal{A}$ = the set of all sampled farms in the reference area used to estimate the maximum proportion of soil carbon loss	
Section References	6.5.7	
Comments	Estimated uncertainty of the soil carbon loss model This assumes a normal approximation. This is derived from the standard error of the mean estimated carbon stock in the reference area at the 95% confidence level divided by mean carbon stock in the reference area.	

$C_{BE}^{[m]} = \sum_{j \in \mathcal{C}} C_{BE,j}^{[m]}$		[20]
Variables	$C_{BE}^{[m]}$= estimated baseline emissions $\mathcal{C}$ = the set of all selected carbon pools	
Section References	8	
Comments	A sum of estimated emissions over selected carbon pools	

$C^{[m]}_{BE,AGLT} = F_{DF}\left(t_2^{[m]},\hat{\eta}^{[m]}\right)C^{[m]}_{AGLT} - F_{DF}\left(t^{[m-1]},\hat{\eta}^{[m-1]}\right)C^{[m-1]}_{AGLT}$	[21]
Variables	$C^{[m]}_{BE,AGLT}$ = baseline emissions in above ground large trees for monitoring period $[m]$ $F_{DF}\left(t_2^{[m]},\hat{\eta}^{[m]}\right)$ = predicted proportion of cumulative deforestation at monitoring period $[m]$, given by either equation [16] or a conservative linear model as described in section 6.4.8 $F_{DF}\left(t^{[m-1]},\hat{\eta}^{[m-1]}\right)$ = predicted proportion of cumulative deforestation at monitoring period $[m-1]$, given by either equation [16] or a conservative linear model as described in section 6.4.8 $C^{[m]}_{AGLT}$ = carbon stock in above-ground large trees for monitoring period $[m]$ $C^{[m-1]}_{AGLT}$ = carbon stock in above-ground large trees for monitoring period $[m-1]$
Section References	8.1
Comments	At the first monitoring period, the terms referring to monitoring period $[m-1]$ can be disregarded.

$C^{[m]}_{BE,AGST} = F_{DF}\left(t_2^{[m]},\hat{\eta}^{[m]}\right)C^{[m]}_{AGST} - F_{DF}\left(t^{[m-1]},\hat{\eta}^{[m-1]}\right)C^{[m-1]}_{AGST}$	[22]
Variables	$C^{[m]}_{BE,AGST}$ = baseline emissions in above ground small trees for monitoring period $[m]$ $F_{DF}\left(t_2^{[m]},\hat{\eta}^{[m]}\right)$ = predicted proportion of cumulative deforestation at monitoring period $[m]$, given by either equation [16] or a conservative linear model as described in section 6.4.8 $F_{DF}\left(t^{[m-1]},\hat{\eta}^{[m-1]}\right)$ = predicted proportion of cumulative deforestation at monitoring period $[m-1]$, given by either equation [16] or a conservative linear model as described in section 6.4.8 $C^{[m]}_{AGST}$ = carbon stock in above-ground small trees for monitoring period $[m]$ $C^{[m-1]}_{AGST}$ = carbon stock in above-ground small trees for monitoring period $[m-1]$
Section References	8.2
Comments	At the first monitoring period, the terms referring to monitoring period $[m-1]$ can be disregarded.

$$C_{BE,AGNT}^{[m]} = F_{DF}\left(t_2^{[m]}, \hat{\eta}^{[m]}\right) C_{AGNT}^{[m]} - F_{DF}\left(t_2^{[m-1]}, \hat{\eta}^{[m-1]}\right) C_{AGNT}^{[m-1]}$$	[23]

Variables	$C_{BE,AGNT}^{[m]}$ = baseline emissions in above ground non trees for monitoring period $[m]$ $F_{DF}\left(t_2^{[m]}, \hat{\eta}^{[m]}\right)$ = predicted proportion of cumulative deforestation at monitoring period $[m]$, given by either equation [16] or a conservative linear model as described in section 6.4.8 $F_{DF}\left(t^{[m-1]}, \hat{\eta}^{[m-1]}\right)$ = predicted proportion of cumulative deforestation at monitoring period $[m-1]$, given by either equation [16] or a conservative linear model as described in section 6.4.8 $C_{AGNT}^{[m]}$ = carbon stock in above-ground non trees for monitoring period $[m]$ $C_{AGNT}^{[m-1]}$ = carbon stock in above-ground non trees for monitoring period $[m-1]$
Section References	8.3
Comments	At the first monitoring period, the terms referring to monitoring period $[m-1]$ can be disregarded.

$$C^{[m]}_{BE,BGLT} = p_{BGLT}\left[F_{DF}\left(t_2^{[m]},\hat{\eta}^{[m]}\right)C^{[m]}_{BGLT} - F_{DF}\left(t_2^{[m-1]},\hat{\eta}^{[m-1]}\right)C^{[m-1]}_{BGLT}\right]$$	[24]

Variables	$C^{[m]}_{BE,BGLT}$ = baseline emissions in below ground large trees for monitoring period $[m]$ p_{BGLT} = proportion of below-ground large tree biomass removed as a result of land conversion to agriculture $F_{DF}\left(t_2^{[m]},\hat{\eta}^{[m]}\right)$ = predicted proportion of cumulative deforestation at monitoring period $[m]$, given by either equation [16] or a conservative linear model as described in section 6.4.8 $F_{DF}\left(t^{[m-1]},\hat{\eta}^{[m-1]}\right)$ = predicted proportion of cumulative deforestation at monitoring period $[m-1]$, given by either equation [16] or a conservative linear model as described in section 6.4.8 $C^{[m]}_{BGLT}$ = carbon stock in below ground large trees for monitoring period $[m]$ $C^{[m-1]}_{BGLT}$ = carbon stock in below ground large trees for monitoring period $[m-1]$
Section References	8.4
Comments	At the first monitoring period, the terms referring to monitoring period $[m-1]$ can be disregarded.

$C_{BE,BGST}^{[m]} = F_{DF}\left(t_2^{[m]}, \hat{\eta}^{[m]}\right) C_{BGST}^{[m]} - F_{DF}\left(t_2^{[m-1]}, \hat{\eta}^{[m-1]}\right) C_{BGST}^{[m-1]}$	[25]
Variables	$C_{BE,BGST}^{[m]}$ = baseline emissions in below ground small trees for monitoring period $[m]$ $F_{DF}\left(t_2^{[m]}, \hat{\eta}^{[m]}\right)$ = predicted proportion of cumulative deforestation at monitoring period $[m]$, given by either equation [16] or a conservative linear model as described in section 6.4.8 $F_{DF}\left(t^{[m-1]}, \hat{\eta}^{[m-1]}\right)$ = predicted proportion of cumulative deforestation at monitoring period $[m-1]$, given by either equation [16] or a conservative linear model as described in section 6.4.8 $C_{BGST}^{[m]}$ = carbon stock in below ground small trees for monitoring period $[m]$ $C_{BGST}^{[m-1]}$ = carbon stock in below ground small trees for monitoring period $[m-1]$
Section References	8.5
Comments	At the first monitoring period, the terms referring to monitoring period $[m-1]$ can be disregarded.

$C_{BE,BGNT}^{[m]} = F_{DF}\left(t_2^{[m]}, \hat{\eta}^{[m]}\right) C_{BGNT}^{[m]} - F_{DF}\left(t_2^{[m-1]}, \hat{\eta}^{[m-1]}\right) C_{BGNT}^{[m-1]}$	[26]
Variables	$C_{BE,BGNT}^{[m]}$ = baseline emissions in below ground non trees for monitoring period $[m]$ $F_{DF}\left(t_2^{[m]}, \hat{\eta}^{[m]}\right)$ = predicted proportion of cumulative deforestation at monitoring period $[m]$, given by either equation [16] or a conservative linear model as described in section 6.4.8 $F_{DF}\left(t^{[m-1]}, \hat{\eta}^{[m-1]}\right)$ = predicted proportion of cumulative deforestation at monitoring period $[m-1]$, given by either equation [16] or a conservative linear model as described in section 6.4.8 $C_{BGNT}^{[m]}$ = carbon stock in below ground non trees for monitoring period $[m]$ $C_{BGNT}^{[m-1]}$ = carbon stock in below ground non trees for monitoring period $[m-1]$
Section References	8.6
Comments	At the first monitoring period, the terms referring to monitoring period $[m-1]$ can be disregarded.

$$C_{BE,SDW}^{[m]} = F_{DF}\left(t_2^{[m]}, \hat{\eta}^{[m]}\right) C_{SDW}^{[m]} - F_{DF}\left(t_2^{[m-1]}, \hat{\eta}^{[m-1]}\right) C_{SDW}^{[m-1]}$$	[27]
Variables	$C_{BE,SDW}^{[m]}$ = baseline emissions in standing dead wood for monitoring period $[m]$ $F_{DF}\left(t_2^{[m]}, \hat{\eta}^{[m]}\right)$ = predicted proportion of cumulative deforestation at monitoring period $[m]$, given by either equation [16] or a conservative linear model as described in section 6.4.8 $F_{DF}\left(t^{[m-1]}, \hat{\eta}^{[m-1]}\right)$ = predicted proportion of cumulative deforestation at monitoring period $[m-1]$, given by either equation [16] or a conservative linear model as described in section 6.4.8 $C_{SDW}^{[m]}$ = carbon stock in standing dead wood for monitoring period $[m]$ $C_{SDW}^{[m-1]}$ = carbon stock in standing dead wood s for monitoring period $[m-1]$
Section References	8.7
Comments	At the first monitoring period, the terms referring to monitoring period $[m-1]$ can be disregarded.

$$C_{BE,LDW}^{[m]} = F_{DF}\left(t_2^{[m]}, \hat{\eta}^{[m]}\right) C_{LDW}^{[m]} - F_{DF}\left(t_2^{[m-1]}, \hat{\eta}^{[m-1]}\right) C_{LDW}^{[m-1]}$$	[28]
Variables	$C_{BE,LDW}^{[m]}$ = baseline emissions in lying dead wood for monitoring period $[m]$ $F_{DF}\left(t_2^{[m]}, \hat{\eta}^{[m]}\right)$ = predicted proportion of cumulative deforestation at monitoring period $[m]$, given by either equation [16] or a conservative linear model as described in section 6.4.8 $F_{DF}\left(t^{[m-1]}, \hat{\eta}^{[m-1]}\right)$ = predicted proportion of cumulative deforestation at monitoring period $[m-1]$, given by either equation [16] or a conservative linear model as described in section 6.4.8 $C_{LDW}^{[m]}$ = carbon stock in lying dead wood for monitoring period $[m]$ $C_{LDW}^{[m-1]}$ = carbon stock in lying dead wood s for monitoring period $[m-1]$
Section References	8.8
Comments	At the first monitoring period, the terms referring to monitoring period $[m-1]$ can be disregarded.

$C_{BE,SOIL}^{[m]} = \sum_{i\in\mathcal{M}} S\left(t_2^{[m-1]} - t_2^{[m-i-1]}, t_2^{[m]} - t_2^{[m-i]}, \hat{\lambda}, \hat{\ell}_{max}\right)\left[F_{DF}\left(t_2^{[m-i]}, \hat{\eta}^{[m-i]}\right) - F_{DF}\left(t_2^{[m-i-1]}, \hat{\eta}^{[m-i-1]}\right)\right] C_{SOIL}^{[m-i]}$	[29]
Variables	$C_{BE,SOIL}^{[m]}$ = baseline emissions in soil for monitoring period $[m]$ $S\left(t_2^{[m-1]} - t_2^{[m-i-1]}, t_2^{[m]} - t_2^{[m-i]}, \hat{\lambda}, \hat{\ell}_{max}\right)$ = the soil carbon loss function defined in equation [18] t_i = the time of the i^{th} sample point $\hat{\ell}_{max}$ = the estimated maximum proportion of soil carbon lost over time $\hat{\lambda}$ = estimated mean rate of soil carbon loss $F_{DF}\left(t_2^{[m]}, \hat{\eta}^{[m]}\right)$ = predicted proportion of cumulative deforestation at monitoring period $[m]$, given by either equation [16] or a conservative linear model as described in section 6.4.8 $C_{SOIL}^{[m-i]}$ = carbon stock in soil for monitoring period $[m-i]$ $\mathcal{M}$ = the set of all monitoring periods including $[m]$ where the first monitoring period is $m = 0$.
Section References	8.9
Comments	S is the soil carbon loss function defined in equation [18]. At the first monitoring period, the terms referring to monitoring period $[m-1]$ and $[m-i-1]$ can be disregarded.

$$C_{BE,WP}^{[m]} = -r_{WP} \times C_{BE,AGLT}^{[m]}$$	[30]
Variables	$C_{BE,WP}^{[m]}$ = baseline emissions in wood products for monitoring period $[m]$ r_{WP} = proportion of above-ground large tree biomass converted to long-lived wood products $C_{BE,AGLT}^{[m]}$ = baseline emissions in above-ground large trees for monitoring period $[m]$
Section References	8.10
Comments	This equation estimates the baseline carbon stock in wood products for monitoring period $[m]$

$$C_{PE}^{[m]} = \frac{44}{12} \times \sum_{i \in \mathcal{E}} cf_{sp} \times m_{burned,i}^{[m]} \times (1 - 0.33)$$	[31]
Variables	$C_{PE}^{[m]}$ = estimated project emissions cf_{sp} = carbon fraction of dry matter for species sp $m_{burned,i}^{[m]}$ = the mass of wood burned during the i^{th} event $\mathcal{E}$ = the set of all burning events
Section References	9.1
Comments	This equation estimates emissions from biomass burning. $(1 - 0.33)$ Accounts for the proportion of mass burned assumed to be water (Simpson & Sagoe, 1991). $\frac{44}{12}$is the ratio of the mass of carbon dioxide to the mass of carbon and is used to convert to CO2e units.

$$C_{LE}^{[m]} = \hat{r}_{LE}^{[m]} C_{BE}^{[m]}$$	[32]

Variables	$C_{LE}^{[m]}$ = estimated emissions from leakage for monitoring period $[m]$ $\hat{r}_{LE}^{[m]}$ = estimated leakage factor for monitoring period $[m]$ $C_{BE}^{[m]}$ = estimated baseline emissions for monitoring period $[m]$
Section References	10
Comments	This equation estimates emissions from leakage.

$$Let\ \bar{o}^{[m]} = \frac{1}{\#(\mathcal{J}^{[m]})}\sum_{i\in\mathcal{J}^{[m]}} o_i$$

$$Let\ x = max\left\{\begin{array}{c} F_{LE}\left(t_2^{[m]}, \hat{\eta}^{[m]}, \hat{\delta}_{LE}\right) \\ F_{LE}\left(t_2^{[reevaluation-1]}, \hat{\eta}^{[reevaluation-1]}, \hat{\delta}_{LE}\right) \\ \bar{o}^{[m-1]} \end{array}\right.$$

$$\hat{r}_{LE}^{[m]} = \frac{a_{LE}}{p_{forest}a_{project}} \times \begin{cases} 0\ if\,\bar{o}^{[m]} - x \le 0 \\ \bar{o}^{[m]} - x\ o.w. \end{cases}$$

[33]

Variables	$\hat{r}_{LE}^{[m]}$ = leakage factor for monitoring period $[m]$ $\bar{o}^{[m]}$, $\bar{o}^{[m-1]}$ = average of observations taken in the leakage area at monitoring period $[m]$ or $[m-1]$ x = the maximum of the three terms given above $\mathcal{J}^{[m]}$ = set of all observations taken in the leakage area at monitoring period $[m]$ $F_{LE}\left(t_2^{[m]}, \hat{\eta}^{[m]}, \hat{\delta}_{LE}\right)$ = prediction of the cumulative leakage model at monitoring period $[m]$ $F_{LE}\left(t_2^{[reevaluation-1]}, \hat{\eta}^{[reevaluation-1]}, \hat{\delta}_{LE}\right)$ = prediction of the cumulative leakage model prior to the last baseline reevaluation a_{LE} = the area of the leakage area $a_{project}$ = the total project area p_{forest} = the proportion of the project area that is forested
Section References	10.3.3
Comments	This equation is used to estimate the leakage factor. $\bar{o}^{[m]}$ is simply the average of observations taken in the leakage area at monitoring period $[m]$. The leakage factor is estimated as the difference between $\bar{o}^{[m]}$ and the maximum of three options: (1) the prediction of the leakage model at monitoring period $[m]$ (2) the observed leakage in the previous monitoring period. This is necessary to avoid double counting as illustrated in Figure 12. (3) The prediction of the leakage model at the last monitoring period prior to baseline re-evaluation. This is necessary to insure that previous leakage is still properly accounted for (not credited back to the project) after baseline re-evaluation if the prediction of the leakage model decreases as a result of re-evaluation The leakage factor can never be negative.

$$C^{[m]} = C_{BE}^{[m]} - C_{U}^{[m]} - C_{PE}^{[m]} - C_{LE}^{[m]}$$		[34]
Variables	$C^{[m]}$ = net GHG Emission Reductions and Removals (NERs) for monitoring period $[m]$ $C_{BE}^{[m]}$ = estimated baseline emissions for monitoring period $[m]$ $C_{U}^{[m]}$ = confidence deduction for monitoring period $[m]$ $C_{PE}^{[m]}$ = estimated project emissions for monitoring period $[m]$ $C_{LE}^{[m]}$ = estimated emissions from leakage for monitoring period $[m]$	
Section References	11, 11.1, 11.3	
Comments	This equation estimates total net GHG Emission Reductions and Removals (NERs) for monitoring period $[m]$	

$$C_{U}^{[m]} = \begin{cases} 0 \; if \; U^{[m]} \leq 0.15 \\ \dfrac{C_{BE}^{[m]}\left(U^{[m]} - \; 0.15\right)}{1 - 0.15} \; o.w. \end{cases}$$		[35]
Variables	$C_{U}^{[m]}$ = confidence deduction $U^{[m]}$ = average uncertainty in carbon stocks and the baseline model $C_{BE}^{[m]}$ = estimated baseline emissions for monitoring period $[m]$	
Section References	11.1	
Comments	This equation applies a confidence deduction if the uncertainty in project stock estimates is less than an allowable error of 15% of the mean.	

$U^{[m]} = \sqrt{\left[C_{TOTAL}^{[m]} U_{DF}^{2} + C_{TOTAL}^{[m]} \left(U_{TOTAL}^{[m]}\right)^{2} + C_{SOIL}^{[m]} U_{SCL}^{2}\right] \left(2C_{TOTAL}^{[m]} + C_{SOIL}^{[m]}\right)^{-1}}$	[36]
Variables	$U^{[m]}$ = average uncertainty in carbon stocks and the baseline model at monitoring period $[m]$ U_{DF}^{2} = estimated uncertainty in the cumulative deforestation model $C_{TOTAL}^{[m]}$ = estimated total carbon stock in the project area at monitoring period $[m]$ $U_{TOTAL}^{[m]}$ = estimated uncertainty of total carbon stocks at monitoring period $[m]$ $C_{SOIL}^{[m]}$ = estimated soil carbon stock in the project area at monitoring period $[m]$ U_{SCL}^{2} = = estimated uncertainty in the soil carbon loss model
Section References	11.1
Comments	This equation estimates the average uncertainty in carbon stocks and the baseline model.

$\hat{n}_{TOTAL} = \frac{1}{\left(\frac{0.15\times\bar{C}}{1.96\times\hat{\sigma}_{\bar{C}}}\right)^{2} + \frac{a_{plot}}{a_{project}}}$	[37]
Variables	$\hat{n}_{TOTAL}$ = estimated total number of plots required $\bar{C}$ = estimated mean carbon stock in the project area $\hat{\sigma}_{\bar{C}}$ = estimated standard deviation of carbon stocks in project area a_{plot} = area of a plot $a_{project}$ = total project area
Section References	13.3.1
Comments	This equation is used to estimate sample size when stratum-specific estimates of standard deviation are unavailable. 0.15 represents an allowable error of 15% of the mean, while 1.96 represents the Z statistic from a normal distribution associated with the 95% confidence level. (Avery & Burkhart, 2002)

$$\hat{n}_k = \hat{n}_{total} \frac{a_k}{a_{project}}$$	[38]
Variables	$\hat{n}_k$ = estimated total number of plots required in stratum k $\hat{n}_{TOTAL}$ = estimated total number of plots required a_k = area of stratum k $a_{project}$ = total project area
Section References	13.3.1
Comments	This equation is used to estimate the required number of plots in stratum *k* under proportional allocation. (Avery & Burkhart, 2002)

$$w_k = \frac{a_k \hat{\sigma}_k}{\sum_{j \in \mathcal{S}} a_j \hat{\sigma}_j}$$	[39]
Variables	w_k = the proportion of plots allocated to stratum k a_j or a_k = area of stratum j or k $\hat{\sigma}_j$ or $\hat{\sigma}_k$= estimated standard deviation of carbon stocks in stratum j or k $\mathcal{S}$ = set of all strata in the project area.
Section References	13.3.1
Comments	This equation is used to estimate the proportion of plots in each stratum under Neyman allocation. (Avery & Burkhart, 2002; Shiver & Borders, 1996)

$$w_k = \frac{a_k \hat{\sigma}_k / \sqrt{c_k}}{\sum_{j \in \mathcal{S}} a_j \, \hat{\sigma}_j / \sqrt{c_j}} \qquad [40]$$

Variables	w_k = the proportion of plots allocated to stratum k a_j or a_k = area of stratum j or k $\hat{\sigma}_j$ or $\hat{\sigma}_k$= estimated standard deviation of carbon stocks in stratum j or k $\mathcal{S}$ = set of all strata in the project area. c_j or c_k= estimated cost of sampling carbon stocks in stratum j or k
Section References	13.3.1
Comments	This equation is used to estimate the proportion of plots in each stratum under optimal allocation. (Shiver & Borders, 1996)

$$\hat{n}_{total} = \frac{\sum_{k \in \mathcal{S}} \frac{a_k^2 \hat{\sigma}_k^2}{w_k}}{\left(\frac{0.15 \times a_{project} \times \bar{C}}{1.96 \times a_{plot}}\right)^2 + \sum_{k \in \mathcal{S}} a_k \, \hat{\sigma}_k{}^2} \qquad [41]$$

Variables	$\hat{n}_{TOTAL}$ = estimated total number of plots required (count) a_k = area of stratum k $a_{project}$ = total project area w_k = the proportion of plots allocated to stratum k $\bar{C}$ = estimated mean carbon stock in the project area $\hat{\sigma}_k$= estimated standard deviation of carbon stocks in stratum k $\mathcal{S}$ = set of all strata in the project area
Section References	13.3.1
Comments	This equation is used to estimate the total sample size of a stratified sample. (Avery & Burkhart, 2002; Shiver & Borders, 1996)

$$\hat{n}_k = \hat{n}_{total} w_k$$	[42]
Variables	$\hat{n}_{TOTAL}$ = estimated total number of plots required $\hat{n}_k$ = estimated total number of plots required in stratum k w_k = the proportion of plots allocated to stratum k
Section References	13.3.1
Comments	This equation is used to estimate the number of plots in each stratum. (Shiver & Borders, 1996)

$$\hat{\sigma}_2^2 = \hat{\sigma}_1^2 \sqrt{\frac{a_1}{a_2}}$$	[43]
Variables	$\hat{\sigma}_2^2$= variance of plot of size 2 (unknown plot) $\hat{\sigma}_1^2$ = variance of plot size 1 (known plot) a_1 = area of plot of size 1 a_2 = area of plot of size 2
Section References	13.3.2
Comments	This equation is used to estimate the effect of changing plot area on standard deviation. $a_1$is assumed to be a plot area associated with an estimated variance $\hat{\sigma}_1^2$, while a_2 is the plot area for which variance is to be estimated. (Freese, 1962)

$$\sum_{k \in \mathcal{S}} \frac{a_k}{n_k} \sum_{j \in \mathcal{P}_k} y_{j,k}$$		[44]
Variables	a_k = the area of stratum k n_k = number of plots in stratum k $y_{j,k}$= a quantity estimated for or measured on plot j in stratum k $\mathcal{P}_k$ = set of all plots in stratum k $\mathcal{S}$ = set of all strata in the project area.	
Section References	13.5.1, 13.5.2, 13.5.3, 13.6.1, 13.6.2, 13.6.3, 13.7	
Comments	This is a generic equation used to estimate project level totals from plot level estimates.	

$$y_{j,k} = \frac{1}{a_{j,k}} \sum_{i \in \mathcal{X}_{j,k}} x_{i,j,k}$$		[45]
Variables	$y_{j,k}$= a quantity estimated for or measured on plot j in stratum k $a_{j,k}$ = area of plot j in stratum k $x_{i,j,k}$ = a quantity estimated for or measured for individual i on plot j in stratum k $\mathcal{X}_{j,k}$ = set of all measurements of a type in plot j in stratum k	
Section References	13.5.1, 13.5.2, 13.5.3, 13.6.1, 13.6.2, 13.6.3, 13.7	
Comments	This is a generic equation used to estimate plot level totals expressed per unit area from measurements made on individuals.	

$$\hat{\sigma}_k^2 = \frac{\sum_{j\in\mathcal{P}_k}\left(y_{j,k}\right)^2 - \left(\sum_{j\in\mathcal{P}_k} y_{j,k}\right)^2/\#(\mathcal{P}_k)}{\#(\mathcal{P}_k) - 1}$$

[46]

Variables	$\hat{\sigma}_k^2$ = estimated variance in stratum k $y_{j,k}$= a quantity estimated for or measured on plot j in stratum k $\mathcal{P}_k$ = set of all plots in stratum k
Section References	13.3.1, 13.5.1, 13.5.2, 13.5.3, 13.6.1, 13.6.2, 13.6.3, 13.7, 13.9
Comments	The equation is used to estimate the within-stratum variance of the variable y for stratum k.

$$\hat{\sigma}_{SE} = \sqrt{\sum_{k\in\mathcal{S}}\left[\frac{a_k^2\hat{\sigma}_k^2}{\#(\mathcal{P}_k)}\left(\frac{N_{P,k} - \#(\mathcal{P}_k)}{N_{P,k}}\right)\right]}$$

[47]

Variables	$\hat{\sigma}_{SE}$ = estimated standard error $\hat{\sigma}_k^2$ = estimated variance in stratum k a_k = area of stratum k $N_{P,k}$ = total number of possible plots in stratum k $\mathcal{P}_k$ = set of all plots in stratum k $\mathcal{S}$ = set of all strata in the project area
Section References	13.5.1, 13.5.2, 13.5.3, 13.6.1, 13.6.2, 13.6.3, 13.7
Comments	This equation is used to estimate the standard error of the total from a stratified sample from a finite population. (Shiver & Borders, 1996)

$\hat{\sigma}_{SE,LDW} = \sqrt{\sum_{k\epsilon\mathcal{S}}\left[\frac{a_k^2\hat{\sigma}_k^2}{\#(\mathcal{L}_k)}\right]}$	[48]
Variables	$\hat{\sigma}_{SE,LDW}$ = estimated standard error of carbon stock in lying dead wood a_k = the area of stratum k $\hat{\sigma}_k^2$ = estimated variance of lying dead wood samples in stratum k $\mathcal{S}$ = set of all strata in the project area $\mathcal{L}_k$ = set of all transects used for measurement of lying dead wood in stratum k
Section References	13.8
Comments	This equation is used to estimate the standard error of the total from a line intersect sample used to estimate carbon in lying dead wood. (Shiver & Borders, 1996)

$\hat{\sigma}_{SE,SOIL} = \sqrt{\sum_{k\epsilon\mathcal{S}}\frac{a_k^2\sigma_k^2}{\#(\mathcal{P}_k)}}$	[49]
	$\hat{\sigma}_{SE,SOIL}$ = estimated standard error of carbon stock in soil a_k = the area of stratum k $a_{project}$ = the total project area $\hat{\sigma}_k^2$ = estimated variance of soil samples in stratum k $\mathcal{S}$ = set of all strata in the project area $\mathcal{P}_k$ = set of all plots in stratum k
Section References	13.9
Comments	This equation is used to estimate the standard error of total soil carbon stocks. (Avery & Burkhart, 2002; Shiver & Borders, 1996)

$x_{i,j,k} = \frac{44}{12} \times \frac{1}{1{,}000} \times f_{sp}(\bullet) \times cf_{sp}$	[50]
Variables	$x_{i,j,k}$ = carbon stock in CO_2e represented by tree i on plot j in stratum k $f_{sp}(\bullet)$ = allometric equation for species sp cf_{sp}= carbon fraction for species sp
Section References	13.5.1, 13.5.2, 13.6.1, 13.6.2, 13.7
Comments	This equation is used to estimate the carbon stock for the i^{th} tree in plot j, stratum k. $\frac{44}{12}$ is the ratio of the mass of carbon dioxide to the mass of carbon and is used to convert to CO2e units. $\frac{1}{1{,}000}$ represents a conversion from kg to tonnes.

$x_{i,j,k} = \frac{44}{12} \times \frac{1}{1{,}000} \times cf_{sp} \times \rho_{sp} \times v_{i,j,k}$	[51]
Variables	$x_{i,j,k}$ = carbon stock for the i^{th} tree in decay class II in plot j, stratum k cf_{sp} = carbon fraction for species sp ρ_{sp} = wood density of species sp $v_{i,j,k}$ = volume of the i^{th} tree in decay class II in plot j, stratum k
Section References	13.7
Comments	This equation is used to estimate the carbon stock for the i^{th} tree in decay class II in plot j, stratum k. $\frac{44}{12}$is the ratio of the mass of carbon dioxide to the mass of carbon and is used to convert to CO2e units. $\frac{1}{1{,}000}$represents a conversion from kg to tonnes.

$v_{i,j,k} = \frac{\pi h_{i,j,k}(r_{BASE,i,j,k}^2 + r_{TOP,i,j,k}^2 + r_{BASE,i,j,k} \times r_{TOP,i,j,k})}{3}$		[52]
	$v_{i,j,k}$ = volume of the i^{th} tree in decay class II in plot j, stratum k $h_{i,j,k}$ = height of the i^{th} tree in plot j in stratum k $r_{BASE,i,j,k}$ = base radius of the i^{th} tree in plot j in stratum k $r_{TOP,i,j,k}$ = top radius of the i^{th} tree in plot j in stratum k	
Section References	13.7	
Comments	This equation is the volume of a truncated cone and is used to estimate the bole volume of standing dead trees in decay class II. Units for radius and height must be given in meters.	

$y_{j,k} = \frac{44}{12} \times \frac{1}{1,000} \times \frac{cf_{sp} \times m_{dry,j,k}}{a_{j,k}}$		[53]
Variables	$y_{j,k}$ = carbon stock in non-tree biomass that results from a destructive sample cf_{sp} = carbon fraction for species sp $a_{j,k}$ = area of plot j in stratum k $m_{dry,j,k}$ = dry mass of non-tree sample harvested from clip plots in plot j, stratum k	
Section References	13.5.3	
Comments	This equation is used to estimate the carbon stock in non-tree biomass that results from a destructive sample. $\frac{44}{12}$is the ratio of the mass of carbon dioxide to the mass of carbon and is used to convert to CO2e units. $\frac{1}{1,000}$represents a conversion from kg to tonnes.	

$$x_{i,j,k} = \frac{44}{12} \times \frac{1}{1{,}000} \times f_{sp}(\boldsymbol{v}) \times cf_{sp}$$	[54]

Variables	$x_{i,j,k}$ = carbon stock in CO_2e represented by non-tree i on plot j in stratum k $f_{sp}(\bullet)$ = allometric equation for species sp cf_{sp}= carbon fraction for species sp
Section References	13.5.3
Comments	This equation is used to estimate the carbon stock in non-tree biomass that results from using the allometric equation method. $\frac{44}{12}$is the ratio of the mass of carbon dioxide to the mass of carbon and is used to convert to CO2e units. $\frac{1}{1{,}000}$represents a conversion from kg to tonnes.

$$m_{dry,j,k} = m_{wet,j,k} \frac{m_{dry,subsample}}{m_{wet,subsample}}$$	[55]

Variables	$m_{dry,j,k}$ = dry mass of non-tree sample harvested from clip plots in plot j, stratum k $m_{wet,j,k}$ = wet mass of non-tree sample harvested from clip plots in plot j, stratum k $m_{dry,subsample}$ = dry mass of subsample of non-tree biomass collected to estimate dry:wet ratio $m_{wet,subsample}$= wet mass of subsample of non-tree biomass collected to estimate dry:wet ratio
Section References	13.5.3
Comments	This equation is used to estimate dry biomass as a function of the ratio of dry to wet biomass in a subsample of harvested vegetation.

$$y_k = \frac{\sum_{j \in \mathcal{L}_k} l_j y_{j,k}}{\sum_{j \in \mathcal{L}_k} l_j}$$	[56]
Variables	y_k = average carbon stock per unit area in lying dead wood in stratum k l_j = length of transect j used for measuring lying dead wood. $y_{j,k}$ = total carbon stock in lying dead wood for stratum k transect j $\mathcal{L}_k$ = set of all transects used for measurement of lying dead wood in stratum k
Section References	13.8
Comments	This equation is used to estimate the total carbon stock in lying dead wood in stratum k. This equation is a weighted average where the weights are proportional to transect length. In the common case where all transects are the same length, it simplifies to the average: $y_k = \frac{1}{\#(\mathcal{L}_k)} \sum_{j \in \mathcal{L}_k} y_{j,k}$ (Shiver & Borders, 1996)

$$\hat{\sigma}_k^2 = \frac{\sum_{j \in \mathcal{L}_k} \left(y_{j,k}\right)^2 - \left(\sum_{j \in \mathcal{L}_k} y_{j,k}\right)^2 / \#(\mathcal{L}_k)}{\#(\mathcal{L}_k) - 1}$$	[57]
Variables	$\hat{\sigma}_k^2$ = variance of carbon stock in lying dead wood for stratum k transect j $y_{j,k}$ = total carbon stock in lying dead wood for stratum k transect j $\mathcal{L}_k$ = set of all transects used for measurement of lying dead wood in stratum k
Section References	13.8
Comments	This equation is used to estimate the variance of carbon in lying dead wood in stratum k

$y_{j,k} = \frac{44}{12} \times \frac{1}{10,000} \times \frac{1}{1,000} \times \sum_{d \in \mathcal{D}} \frac{cf_{dw} \times \bar{\rho}_d \times \pi^2 \sum_{i \in \mathcal{X}_{j,k}} x_{i,j,k,d}^2}{8 l_j}$	[58]
Variables	$y_{j,k}$ = total carbon stock in lying dead wood for stratum k transect j cf_{dw} = carbon fraction of dry matter for dead wood $\bar{\rho}_d$= average density of dead wood in decay class d $x_{i,j,k,d}$ = diameter of i^{th} piece of lying dead wood on transect j in stratum k, decay class d l_j = length of transect j $\mathcal{D}$ = the set of all decay classes $\mathcal{X}_{j,k}$ = set of all measurements of lying dead wood in plot j in stratum k
Section References	13.8
Comments	This equation is used to estimate the carbon stock in lying dead wood per unit area for stratum k transect j The variables $x_{i,j,k,d}$ and l_j must be measured in meters. $\frac{44}{12}$ is the ratio of the mass of carbon dioxide to the mass of carbon and is used to convert to CO2e units. $\frac{1}{1,000}$ represents a conversion from kg to tonnes. $\frac{1}{10,000}$ represents a conversion from m^2 to hectares.

$C_{LDW}^{[m]} = \sum_{k \in \mathcal{S}} a_k y_k$	[59]
Variables	$C_{LDW}^{[m]}$ = estimated carbon stock in lying dead wood at monitoring period $[m]$ a_k = area of stratum k y_k = average carbon stock per unit area in lying dead wood in stratum k
Section References	13.8
Comments	This equation is used to estimate the total carbon stock in lying dead wood.

$$\rho_{soil,j,k} = \frac{m_{soil,j,k} - m_{rf,j,k}}{v_{soil,j,k} - v_{rf,j,k}}$$		[60]
Variables	$\rho_{soil,j,k}$ = bulk density of fine portion of soil sample in plot j in stratum k $m_{soil,j,k}$ = dry mass of soil sample take from plot j in stratum k. $m_{rf,j,k}$ = dry mass of rock fraction of soil sample in plot j in stratum k $v_{soil,j,k}$ = total volume of soil sample in plot j in stratum k $v_{rf,j,k}$ = volume rock fragments (> 2mm) in soil sample taken in plot j in stratum k	
Section References	13.9	
Comments	This equation estimates the bulk density of soil, corrected to exclude the rock fraction (fragments >2 mm).	

$$y_{j,k} = \frac{44}{12} \times 10 \times cf_{soil,j,k} \times \rho_{soil,j,k} \times d_{j,k} \times (1 - \frac{v_{rf,j,k}}{v_{soil,j,k}})$$		[61]
Variables	$y_{j,k}$ = soil carbon stock in plot j stratum k $\rho_{soil,j,k}$ = bulk density of fine portion of soil sample in plot j in stratum k $cf_{soil,j,k}$ = carbon fraction of soil sample in plot j in stratum k $d_{j,k}$ = depth of soil sample in plot j in stratum k $v_{soil,j,k}$ = total volume of soil sample in plot j in stratum k $v_{rf,j,k}$ = volume rock fragments (> 2mm) in soil sample taken in plot j in stratum k	
Section References	13.9	
Comments	This equation is used to estimate the carbon stock in soil in stratum k plot j $\frac{44}{12}$is the ratio of the mass of carbon dioxide to the mass of carbon and is used to convert to CO2e units. The conversion factor 10 represents a conversion from kg to tones and from m^{-2} to ha^{-1}.	

$C_{TOTAL}^{[m]} = \sum_{j \in \mathcal{C}} C_j^{[m]}$		[62]
Variables	$C_{TOTAL}^{[m]}$ = total carbon stock in the project area at monitoring period $[m]$ $\mathcal{C}$ = the set of selected carbon pools	
Section References	13.4	
Comments	This equation is used to estimate the total carbon stock in all selected carbon pools.	

$\hat{\sigma}_{SE,TOTAL} = \sqrt{\sum_{j \in \mathcal{C}} \left(\hat{\sigma}_{SE,j}^{[m]}\right)^2}$		[63]
Variables	$\hat{\sigma}_{SE,TOTAL}$ = estimated standard error of total carbon stocks in the project area $\mathcal{C}$ = the set of selected carbon pools $\hat{\sigma}_{SE,j}^{[m]}$ = estimated standard error of carbon pool j	
Section References	13.12	
Comments	This equation is used to combine the standard errors of the selected carbon pools.	

$C_{BGNT}^{[m]} = r_{sp} \times C_{AGNT}^{[m]}$		[64]
Variables	$C_{BGNT}^{[m]}$= total carbon stock in below ground non-trees in monitoring period $[m]$ $C_{AGNT}^{[m]}$= total carbon stock in above ground non-trees in monitoring period $[m]$ r_{sp}= root to shoot ratio for non-trees	
Section References	13.6.3	
Comments	This equation is used to estimate the total carbon stock in below-ground non trees. An average of non-tree species specific ratios, or a generic ratio that is appropriate for shrubs in the project area may be used for the parameter r_{sp}.	

$\hat{\sigma}_{SE,BGNT}^{[m]} = r_{sp} \times \hat{\sigma}_{SE,AGNT}^{[m]}$	[65]
Variables	$\hat{\sigma}_{SE,BGNT}^{[m]}$= standard error of carbon stock in below-ground non-trees in monitoring period $[m]$ $\hat{\sigma}_{SE,AGNT}^{[m]}$= standard error of carbon stock in above-ground non-trees in monitoring period $[m]$ r_{sp}= root to shoot ratio for non-trees
Section References	13.6.3
Comments	This equation is used to estimate the standard error of the carbon stock in below-ground non trees. An average of non-tree species specific ratios, or a generic ratio that is appropriate for shrubs in the project area may be used for the parameter r_{sp}.

$y_{j,k} = y_{INTACT,j,k} + y_{DECAYED,j,k}$	[66]
Variables	$y_{j,k}$ = carbon stock in standing dead wood in plot j in stratum k $y_{INTACT,j,k}$ = carbon stock in standing dead wood in decay class I in plot j in stratum k $y_{DECAYED,j,k}$ carbon stock in standing dead wood in decay class II in plot j in stratum k
Section References	13.7
Comments	The equation combines the carbon stocks of standing dead trees in different decay classes.

$U_{TOTAL}^{[m]} = 1.96 \frac{\hat{\sigma}_{SE,TOTAL}^{[m]}}{C_{TOTAL}^{[m]}}$	[67]
Variables	$U_{TOTAL}^{[m]}$ = estimated percent uncertainty of total carbon stocks $\hat{\sigma}_{SE,TOTAL}^{[m]}$ = estimated standard error of total carbon stock $C_{TOTAL}^{[m]}$ = estimated total carbon stock
Section References	13.12
Comments	This equation is used to estimate the total uncertainty in carbon stocks as a percentage of the mean at a 95% confidence level. 1.96 represents the Z statistic for a 95% confidence level from a normal distribution.

$\hat{y}_i = f_{-i}(x_i)$	[68]
Variables	$\hat{y}_i$ = predicted value for observation i f_{-i}= model fit using all points in dataset except observation i x_i = independent variable associated with observation i
Section References	13.13.1
Comments	This is the predicted value at observation i that results from fitting a model using all points but observation i during cross validation.

$\hat{e}_i = \frac{\hat{y}_i - y_i}{y_i} \times 100\%$	[69]
Variables	$\hat{e}_i$ = cross-validated residual for observation i $\hat{y}_i$ = predicted value for observation i y_i = observed dependent variable for observation i
Section References	13.13.1
Comments	This is the cross validated residual for point *i*, expressed as a percentage.

$$\bar{E} = \frac{\sum_{i \in \mathcal{X}} \hat{e}_i}{\#(\mathcal{X})}$$		[70]
Variables	$\bar{E}$ = mean cross-validated error $\hat{e}_i$ = cross-validated residual for observation i $\mathcal{X}$ = the set of all observations	
Section References	13.13.1	
Comments	This equation estimates mean cross-validated error, a measure of bias in the dataset $\mathcal{X}$.	

Appendix B: List of Variables

Data / Parameter:	$\mathcal{A}$
Data Unit:	Set
Description:	The set of all sampled farms in the reference area used to estimate the maximum proportion of soil carbon loss
Source of Data:	A sample of farms in the reference area.
Used in Equations:	[12]
Frequency of monitoring/recording:	Observed once prior to the end of the first monitoring period, held constant over entire project lifetime.
Comment:	

Data / Parameter:	$\mathcal{C}$
Data Unit:	Set
Description:	The set of all selected carbon pools
Source of Data:	Includes all required and selected optional carbon pools
Used in Equations:	[20]
Frequency of monitoring/recording:	Held constant over entire project lifetime.
Comment:	

Data / Parameter:	$\mathcal{D}$
Data Unit:	Set
Description:	The set of all decay classes
Source of Data:	Decay classes are sound, intermediate, and rotten.
Used in Equations:	[58]
Frequency of monitoring/recording:	Held constant over entire project lifetime.
Comment:	

Data / Parameter:	$\mathcal{E}$
Data Unit:	Set
Description:	The set of all burning events
Source of Data:	Records of biomass burning and charcoal production in the project area
Used in Equations:	[31]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$\mathcal{J}, \mathcal{J}^{[m]}$
Data Unit:	Set
Description:	The set of all observations of deforestation. When superscripted with a monitoring period, the deforestation observations are taken for leakage analysis.
Source of Data:	Remote sensing image interpretation or field observations in the leakage area.
Used in Equations:	[17]
Frequency of monitoring/recording:	Re-evaluated whenever the baseline model is re-assessed or, for leakage analysis, at every monitoring period.
Comment:	

Data / Parameter:	$\mathcal{L}_k$
Data Unit:	Set
Description:	Set of all transects used for measurement of lying dead wood in stratum k
Source of Data:	Field measurements
Used in Equations:	[48], [56], [57]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	Note that two transects are generally measured at the location of each plot, so the number of elements in this set is twice the number of plots measured.

Data / Parameter:	$\mathcal{M}$
Data Unit:	Set
Description:	The set of all monitoring periods prior to $[m]$
Source of Data:	
Used in Equations:	[29]
Frequency of monitoring/recording:	
Comment:	

Data / Parameter:	$\mathcal{P}_k$
Data Unit:	Set
Description:	Set of all plots in stratum k
Source of Data:	Field measurements
Used in Equations:	[44], [46], [47], [49]
Frequency of monitoring/recording:	Determined at first carbon inventory. May be updated prior to additional carbon inventories.
Comment:	

Data / Parameter:	$\mathcal{S}$
Data Unit:	Set
Description:	Set of all strata in the project area.
Source of Data:	Stratification carried out based on guidance in section 13.2 .
Used in Equations:	[39], [40], [41], [44], [47], [48], [49]
Frequency of monitoring/recording:	Determined at first carbon inventory. May be updated prior to additional carbon inventories.
Comment:	

Data / Parameter:	$\mathcal{X}_{j,k}$
Data Unit:	Set
Description:	Set of all measurements of a type in plot j in stratum k
Source of Data:	Field measurements
Used in Equations:	[45], [58]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	This is a generic variable that may stand in for variables of different types in different contexts. For example, it may stand for the set of all tree diameter measurements made on a plot.

Data / Parameter:	α
Data Unit:	Real
Description:	Intercept of linear predictor of cumulative deforestation model
Source of Data:	Parameter of model fit to observations of deforestation given time and a vector of deforestation covariates. See equation [7] and section 6.4.7 for details.
Used in Equations:	[7] , [9]
Frequency of monitoring/recording:	Re-evaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	β
Data Unit:	Real
Description:	Time parameter of linear predictor of cumulative deforestation model
Source of Data:	Parameter of model fit to observations of deforestation given time and a vector of deforestation covariates. See equation [7] and section 6.4.7 for details.
Used in Equations:	[7], [9]
Frequency of monitoring/recording:	Re-evaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	$\delta_{LE}, \hat{\delta}_{LE}$
Data Unit:	Time
Description:	Lag parameter of leakage model.
Source of Data:	Estimated at project start based on cumulative deforestation model and sample of plots in the leakage area. See equation [9].
Used in Equations:	[8]
Frequency of monitoring/recording:	Estimated at beginning of project.
Comment:	

Data / Parameter:	η
Data Unit:	Real
Description:	Linear predictor of cumulative deforestation model
Source of Data:	Estimated as $\hat{\eta}$ using a model fit to observations of deforestation given time and a vector of deforestation covariates. See equation [7] and section 6.4.7 for details.
Used in Equations:	[16]
Frequency of monitoring/recording:	Re-evaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	$\hat{\eta}$
Data Unit:	Real
Description:	Estimated linear predictor of cumulative deforestation model
Source of Data:	Model fit to observations of deforestation given time and a vector of deforestation covariates. See equation [7] and section 6.4.7 for details.
Used in Equations:	[21], [22], [23], [24], [25], [26], [27], [28], [29], [33]
Frequency of monitoring/recording:	Re-evaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	$\boldsymbol{\theta}$
Data Unit:	Real, vector
Description:	Parameter vector of cumulative deforestation model
Source of Data:	Parameter of model fit to observations of deforestation given time and a vector of deforestation covariates. See equation [7] and section 6.4.7 for details.
Used in Equations:	[7], [16], [9]
Frequency of monitoring/recording:	Re-evaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	λ
Data Unit:	Proportion
Description:	Exponential soil carbon decay parameter
Source of Data:	Estimated as $\hat{\lambda}$ = 0.2 per default or from literature. See discussion in section 6.5 .
Used in Equations:	[11], [13], [14], [18]
Frequency of monitoring/recording:	Re-evaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	$\hat{\lambda}$
Data Unit:	Proportion
Description:	Estimated exponential soil carbon decay parameter
Source of Data:	Calculated using field data. See discussion in section 6.5 .
Used in Equations:	
Frequency of monitoring/recording:	Re-evaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	$\bar{\rho}_d$
Data Unit:	kg m^{-3}
Description:	Mean density of lying dead wood in decay class d
Source of Data:	Field measurements. Calculated as dry mass divided by volume of discs cut from lying dead wood.
Used in Equations:	[58]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	See section 13.8 for further guidance.

Data / Parameter:	$\rho mesoil$
Data Unit:	kg/m^3
Description:	Mass-equivalent bulk density of fine portion of soil sample
Source of Data:	Equation [60]
Used in Equations:	[61]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	Equation [60] estimates the density of the fine portion of the soil for each plot $j$and stratum k by correcting for mass and volume of coarse fragments (> 2 mm). This variable, in turn, represents the mass-equivalent value for bulk density, and is *held constant* for use in equation [61]. ρ_{soil} is the lower of the two *mean values* for bulk density a) within the project area and b) in the reference area for all plots j across all strata .

Data / Parameter:	ρ_{sp}
Data Unit:	kg m^{-3}
Description:	Wood density of species sp
Source of Data:	Species specific data from peer reviewed literature, samples taken on site, or IPCC GPG LULUCG Tables 3A.1.9-1 and 3A.1.9-2.
Used in Equations:	[51]
Frequency of monitoring/recording:	Held constant over entire project lifetime.
Comment:	

Data / Parameter:	$\hat{\sigma}_{SE,AGLT}^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Estimated standard error of carbon stock in above-ground large trees at monitoring period $[m]$
Source of Data:	Calculated using the procedures described in section 13.5.1
Used in Equations:	[63]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$\hat{\sigma}_{SE,AGNT}^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Estimated standard error of carbon stock in above-ground non tree biomass at monitoring period $[m]$
Source of Data:	Calculated using the procedures described in section 13.5.3
Used in Equations:	[63], [65]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$\hat{\sigma}_{SE,AGST}^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Estimated standard error of carbon stock in above-ground small trees at monitoring period $[m]$
Source of Data:	Calculated using the procedures described in section 13.5.2
Used in Equations:	[63]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$\hat{\sigma}_{SE,TOTAL}^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Estimated standard error of total carbon stock in the project area at monitoring period $[m]$
Source of Data:	Calculated from the standard errors of all required and optional carbon pools using equation [63].
Used in Equations:	[67]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$\hat{\sigma}_{\bar{C}}$
Data Unit:	Tonnes CO2e
Description:	Estimated standard deviation of carbon stocks in project area
Source of Data:	Estimated using a pilot sample or literature search prior to sampling.
Used in Equations:	[37]
Frequency of monitoring/recording:	May be updated at each monitoring period.
Comment:	If the sample size is updated in an effort to improve precision between monitoring periods, the standard deviation calculated from previous inventories may be used to update the required sample size.

Data / Parameter:	$\hat{\sigma}_{SE,BGLT}^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Estimated standard error of carbon stock in below-ground large tree biomass at monitoring period $[m]$
Source of Data:	Calculated using the procedures described in section 13.6.1
Used in Equations:	[63]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$\hat{\sigma}_{SE,BGNT}^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Estimated standard error of carbon stock in below-ground non tree biomass at monitoring period $[m]$
Source of Data:	Calculated using the procedures described in section 13.6.3
Used in Equations:	[63]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$\hat{\sigma}_{SE,BGST}^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Estimated standard error of carbon stock in below-ground small tree biomass at monitoring period $[m]$
Source of Data:	Calculated using the procedures described in section 13.6.2
Used in Equations:	[63]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$\hat{\sigma}_{DF}$
Data Unit:	Standard deviation
Description:	The estimated standard deviation of the state observations used to fit the cumulative deforestation model
Source of Data:	Equation [17]
Used in Equations:	[6], [15]
Frequency of monitoring/recording:	Re-evaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	$\hat{\sigma}_k$
Data Unit:	Tonnes CO2e
Description:	Estimated standard deviation of carbon stocks in stratum k.
Source of Data:	Estimated using a pilot sample or literature search prior to sampling when used for sample size estimates. Calculated from field measurements otherwise.
Used in Equations:	[39], [40], [41], [47], [48], [49]
Frequency of monitoring/recording:	May be updated at each monitoring period.
Comment:	If the sample size is updated in an effort improve precision between monitoring periods, the standard deviation calculated from previous inventories may be used to update the required sample size.

Data / Parameter:	$\hat{\sigma}_{SE,LDW}^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Estimated standard error of carbon stock in lying dead wood at monitoring period $[m]$
Source of Data:	Calculated using the procedures described in section 13.8
Used in Equations:	[63]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$\hat{\sigma}_{SE,SDW}^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Estimated standard error of carbon stock in standing dead wood at monitoring period $[m]$
Source of Data:	Calculated using the procedures described in section 13.7
Used in Equations:	[63]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$\hat{\sigma}_{SE,SOIL}^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Estimated standard error of carbon stock in soil carbon at monitoring period $[m]$
Source of Data:	Calculated using the procedures described in section 13.9
Used in Equations:	[63]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$a_{j,k}$
Data Unit:	hectares
Description:	Area of plot j in stratum k
Source of Data:	Specified as part of project sampling design. See guidance in section 13.3.2.
Used in Equations:	[45], [53]
Frequency of monitoring/recording:	May be updated at each monitoring period.
Comment:	

Data / Parameter:	a_k
Data Unit:	hectares
Description:	Area of stratum k.
Source of Data:	GIS analysis prior to sampling. See guidance in section 13.2.
Used in Equations:	[38], [39], [40], [41], [44], [47], [48], [49], [59]
Frequency of monitoring/recording:	May be updated prior to each carbon inventory.
Comment:	The combined area of all strata must be equal to the project area. That is, $\sum_{k \in \mathcal{S}} a_k = a_{project}$.

Data / Parameter:	a_{plot}
Data Unit:	hectares
Description:	Area of a plot.
Source of Data:	Specified as part of project sampling design. See guidance in section 13.3.2.
Used in Equations:	[37], [41]
Frequency of monitoring/recording:	May be updated at each monitoring period.
Comment:	When using this variable to estimate required sample sizes, the area of the plot used to measure the dominant carbon pools in the project should be used. Usually this is the carbon stock in above-ground live trees.

Data / Parameter:	$a_{project}$
Data Unit:	hectares
Description:	Total project area.
Source of Data:	Determined at project validation using surveys and/or GIS analysis.
Used in Equations:	[12], [37], [38], [41], [48], [49], [33]
Frequency of monitoring/recording:	The total project area is fixed at validation.
Comment:	

Data / Parameter:	a_{LE}
Data Unit:	hectares
Description:	Total leakage area.
Source of Data:	Determined at project validation using surveys and/or GIS analysis.
Used in Equations:	[33]
Frequency of monitoring/recording:	The total leakage area is fixed at validation.
Comment:	

Data / Parameter:	$\bar{C}$
Data Unit:	Tonnes CO2e
Description:	Estimated mean carbon stock in the project area.
Source of Data:	Estimated using a pilot sample or literature search prior to sampling.
Used in Equations:	[37], [41]
Frequency of monitoring/recording:	May be updated at each monitoring period.
Comment:	If the sample size is updated in improve precision between monitoring periods, the carbon stock estimates calculated from previous inventories may be used to update the required sample size.

Data / Parameter:	$C^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Quantified emissions reductions and/or removals
Source of Data:	Equation [34]
Used in Equations:	
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	Final estimate of project greenhouse gas benefits (or emissions) for monitoring period $[m]$

Data / Parameter:	$C_{AGLT}^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Estimated carbon stock in above-ground large trees at monitoring period $[m]$
Source of Data:	Calculated using the procedures described in section 13.5.1
Used in Equations:	[21], [62]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$C_{AGNT}^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Estimated carbon stock in above-ground non tree biomass at monitoring period $[m]$
Source of Data:	Calculated using the procedures described in section 13.5.3
Used in Equations:	[23], [64], [62]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$C_{AGST}^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Estimated carbon stock in above-ground small trees at monitoring period $[m]$
Source of Data:	Calculated using the procedures described in section 13.5.2
Used in Equations:	[22], [62]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$C_{BE}^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Estimated baseline emissions
Source of Data:	Equation [20]
Used in Equations:	[20], [32], [34], [35]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$C_{BGLT}^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Estimated carbon stock in below-ground large tree biomass at monitoring period $[m]$
Source of Data:	Calculated using the procedures described in section 13.5.1
Used in Equations:	[24], [62]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$C_{BGST}^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Estimated carbon stock in below-ground small tree biomass at monitoring period $[m]$
Source of Data:	Calculated using the procedures described in section 13.6.2
Used in Equations:	[25], [62]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$C_{BGNT}^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Estimated carbon stock in below-ground non tree biomass at monitoring period $[m]$
Source of Data:	Calculated using the procedures described in section 13.6.3
Used in Equations:	[26], [62]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$C_{LDW}^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Estimated carbon stock in lying dead wood at monitoring period $[m]$
Source of Data:	Calculated using the procedures described in section 13.8
Used in Equations:	[28], [62]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$C_{LE}^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Estimated emissions from leakage
Source of Data:	Equation [32]
Used in Equations:	[34]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$C_{SDW}^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Estimated carbon stock in standing dead wood at monitoring period $[m]$
Source of Data:	Calculated using the procedures described in section 13.7
Used in Equations:	[27], [62]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$C_{SOIL}^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Estimated carbon stock in soil carbon at monitoring period $[m]$
Source of Data:	Calculated using the procedures described in section 13.9
Used in Equations:	[12], [62]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$C_{TOTAL}^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Estimated total carbon stock in the project area at monitoring period $[m]$
Source of Data:	Calculated as the sum of all required and optional carbon pools using equation [62]
Used in Equations:	[67]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$C_U^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Confidence deduction
Source of Data:	Equation [35]
Used in Equations:	[34]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$C_{PE}^{[m]}$
Data Unit:	Tonnes CO2e
Description:	Estimated project emissions
Source of Data:	Equation [31]
Used in Equations:	[34]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	cf_{dw}
Data Unit:	Tonnes carbon per tonne dry matter
Description:	Carbon fraction of dry matter for dead wood
Source of Data:	Where available, data from peer reviewed literature should be used. Where adequate literature is not available, the IPCC default value of 0.5 may be applied.
Used in Equations:	[58]
Frequency of monitoring/recording:	Held constant over entire project lifetime.
Comment:	

Data / Parameter:	$cf_{soil,j,k}$
Data Unit:	kg carbon per kg soil
Description:	Carbon fraction of soil sample in plot j in stratum k
Source of Data:	Estimated from laboratory analysis of soil samples.
Used in Equations:	[61]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	See section 13.9 for additional guidance.

Data / Parameter:	cf_{sp}
Data Unit:	Tonnes carbon per tonne dry matter
Description:	Carbon fraction of dry matter for species sp
Source of Data:	Where available, species specific data from peer reviewed literature should be used. Where adequate literature is not available, the IPCC default value of 0.5 may be applied.
Used in Equations:	[31], [50], [51], [53], [54]
Frequency of monitoring/recording:	Held constant over entire project lifetime.
Comment:	

Data / Parameter:	c_k
Data Unit:	See below
Description:	Relative cost of making an observation in stratum k
Source of Data:	Estimated by project proponent.
Used in Equations:	[40]
Frequency of monitoring/recording:	May be updated at each monitoring period.
Comment:	Only a relative cost is required here, actual currency units need not be used. For example, if the cost of measurement in stratum 1 is twice that of stratum 2, the values 1 and 2 may be used as cost estimates.

Data / Parameter:	$d_{j,k}$
Data Unit:	m
Description:	Depth of soil sample in plot j in stratum k
Source of Data:	Field measurements
Used in Equations:	[61]
Frequency of monitoring/recording:	Must be held constant over entire project lifetime.
Comment:	

Data / Parameter:	$dbh_{i,j,k}$
Data Unit:	Generally measured in centimeters or inches. The measurement units actually used must correspond with the input requirements of the allometric equations selected for the project area.
Description:	Diameter at breast height of the i^{th} tree in plot j in stratum k.
Source of Data:	Field measurements
Used in Equations:	[50]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	Breast height is typically defined as 1.3 meters above the ground. The project proponent must provide clear documentation of tree measurement procedures as described in section 13.11.

Data / Parameter:	$\bar{E}$
Data Unit:	Percent
Description:	Mean cross-validated bias
Source of Data:	Result of cross-validation of newly developed allometric equations. See section 13.13.1.
Used in Equations:	
Frequency of monitoring/recording:	Used only when new allometric equations are developed.
Comment:	

Data / Parameter:	$\hat{e}_i$
Data Unit:	kg
Description:	Estimated cross-validated residual for observation i
Source of Data:	Intermediate variable used in cross-validation of newly developed allometric equations. See section 13.13.1.
Used in Equations:	[70]
Frequency of monitoring/recording:	Used only when new allometric equations are developed.
Comment:	

Data / Parameter:	$f_{-i}(\bullet)$
Data Unit:	Function
Description:	Allometric function re-fit without observation i
Source of Data:	Intermediate variable used in cross-validation of newly developed allometric equations. See section 13.13.1.
Used in Equations:	[69]
Frequency of monitoring/recording:	Used only when new allometric equations are developed.
Comment:	[68]

Data / Parameter:	$f_{sp}(\bullet)$
Data Unit:	Function
Description:	Allometric equation for species sp. For trees, this equation generally is based on dbh and possibly height to biomass. Other variable types may be appropriate for shrubs, so a generic vector of potential independent variables, v, is used in equation description. See guidance in section 13.13.
Source of Data:	Selected from literature or developed by project proponent.
Used in Equations:	[50], [54]
Frequency of monitoring/recording:	Allometric equations are selected or developed and their applicability verified at project verification and are subsequently applied at all monitoring periods.
Comment:	

Data / Parameter:	$G(t,\lambda)$
Data Unit:	Proportion
Description:	Proportion of soil lost at time t with decay parameter λ
Source of Data:	Exponential decay model. See equations [11] and [13].
Used in Equations:	[14]
Frequency of monitoring/recording:	Re-evaluated whenever the baseline model is re-assessed.
Comment:	Further details are given in section 6.5.1

Data / Parameter:	F_{DF}
Data Unit:	Proportion
Description:	Proportion of cumulative deforestation
Source of Data:	Estimated from a model. See equation [16]
Used in Equations:	[21], [22], [23], [24], [25], [26], [27], [28], [29], [33]
Frequency of monitoring/recording:	Predicted from model at each monitoring period.
Comment:	

Data / Parameter:	F_{LE}
Data Unit:	Proportion
Description:	Proportion cumulative deforestation and degradation predicted by the leakage model.
Source of Data:	Estimated from a model. See equation [8].
Used in Equations:	[33]
Frequency of monitoring/recording:	Predicted from model at each monitoring period.
Comment:	

Data / Parameter:	$h_{i,j,k}$
Data Unit:	Generally measured in meters or feet. The measurement units actually used must correspond with the input requirements of the allometric equations selected for the project area. When this variable is an input to equation [52], it must be expressed in meters.
Description:	Height of the i^{th} tree in plot j in stratum k.
Source of Data:	Field measurements
Used in Equations:	[50], [52]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	

Data / Parameter:	l_j
Data Unit:	meters
Description:	Length of transect j used for measuring lying dead wood.
Source of Data:	Field measurements.
Used in Equations:	[56], [58]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	Transects 50 meters in length are suggested. Longer transects may be used to improve inventory precision. All transects should be of the same length.

Data / Parameter:	ℓ_{max}
Data Unit:	Proportion
Description:	The maximum proportion of soil carbon lost over time
Source of Data:	
Used in Equations:	[13], [18]
Frequency of monitoring/recording:	Re-evaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	$\hat{\ell}_{max}$
Data Unit:	proportion
Description:	The estimated maximum proportion of soil carbon lost over time
Source of Data:	Soil carbon is measured on plots that have been converted to agriculture in the reference region and compared to the mean carbon stock in the project area at the initial monitoring period. $\hat{\ell}_{max}$ is estimated as the mean of the loss on these plots.
Used in Equations:	[12]
Frequency of monitoring/recording:	Reevaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	$m_{burned,i}$
Data Unit:	Tonnes
Description:	The mass of wood burned during the i^{th} event
Source of Data:	Records of biomass burning and charcoal production in the project area
Used in Equations:	[31]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$m_{dry,j,k}$
Data Unit:	kg
Description:	Dry mass of non-tree sample harvested from clip plots in plot j, stratum k
Source of Data:	Field measurements. May be estimated from wet mass using equation [55].
Used in Equations:	[53]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	See section 13.5.3 for further guidance.

Data / Parameter:	$\widehat{m}_{DF}$
Data Unit:	Count
Description:	The estimated sample size in the space of the reference area given the pilot sample data
Source of Data:	Equation [6]
Used in Equations:	None. Used to determine number of point sample required in image interpretation.
Frequency of monitoring/recording:	Reevaluated whenever the baseline model is re-assessed.
Comment:	Equation [6] provides a minimum bound on the required sample size. Larger samples can be used to decrease uncertainty in the baseline.

Data / Parameter:	$\hat{m}_{LE}$
Data Unit:	Count
Description:	The estimated sample size in the leakage area.
Source of Data:	Equation [10]
Used in Equations:	None. Used to determine number of point sample required in leakage area.
Frequency of monitoring/recording:	Only observed prior to the end of the first monitoring period.
Comment:	Equation [10] provides a minimum bound on the required sample size. Larger samples can be used to decrease uncertainty in the baseline.

Data / Parameter:	$m_{soil,j,k}$
Data Unit:	kg
Description:	Dry mass of soil sample take from plot j in stratum k.
Source of Data:	Field measurements
Used in Equations:	[60]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	

Data / Parameter:	$m_{rf,j,k}$
Data Unit:	kg
Description:	Dry mass of rock fraction of soil sample in plot j in stratum k
Source of Data:	Field measurements. Soil samples must be sieved to 2 mm and fragments larger than 2mm weighed.
Used in Equations:	[60]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	See section 13.9 for further details.

Data / Parameter:	$m_{dry,subsample}$
Data Unit:	Kg
Description:	Dry mass of subsample of non-tree biomass collected to estimate dry:wet ratio
Source of Data:	Field measurements
Used in Equations:	[55]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	See section 13.5.3 for further guidance.

Data / Parameter:	$m_{wet,j,k}$
Data Unit:	kg
Description:	Wet mass of non-tree sample harvested from clip plots in plot j, stratum k
Source of Data:	Field measurements
Used in Equations:	[55]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	See section 13.5.3 for further guidance.

Data / Parameter:	$m_{wet,subsample}$
Data Unit:	kg
Description:	Wet mass of subsample of non-tree biomass collected to estimate dry:wet ratio
Source of Data:	Field measurements
Used in Equations:	[55]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	See section 13.5.3 for further guidance.

Data / Parameter:	n_{DF}
Data Unit:	Count
Description:	The total number of state observations made to fit the cumulative deforestation model
Source of Data:	Remote sensing image interpretation
Used in Equations:	[15]
Frequency of monitoring/recording:	Reevaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	$\hat{n}_k$
Data Unit:	Count
Description:	Estimated total number of plots required in stratum k.
Source of Data:	Calculated using equation [38] or equation [42].
Used in Equations:	None. Used to guide field sampling design.
Frequency of monitoring/recording:	May be updated if a new sample with greater precision is desired at a monitoring period.
Comment:	

Data / Parameter:	N_P
Data Unit:	Count
Description:	Total number of possible plots in project area
Source of Data:	GIS analysis at the time of stratification
Used in Equations:	[47]
Frequency of monitoring/recording:	Updated whenever stratification is updated.
Comment:	$N_P = \frac{a_{PROJECT}}{a_{PLOT}}$

Data / Parameter:	$N_{P,k}$
Data Unit:	Count
Description:	Total number of possible plots in stratum k
Source of Data:	GIS analysis at the time of stratification
Used in Equations:	[47]
Frequency of monitoring/recording:	Updated whenever stratification is updated.
Comment:	$N_{P,k} = \frac{a_k}{a_{PLOT}}$

Data / Parameter:	n_{SCL}
Data Unit:	Count
Description:	The actual sample size used to estimate the maximum proportion of soil carbon loss in section 6.5.2.
Source of Data:	Equation [19]
Used in Equations:	None. Used to determine number of point sample required in leakage area.
Frequency of monitoring/recording:	Reevaluated whenever the baseline model is re-assessed.
Comment:	See section 6.5.7.

Data / Parameter:	$\hat{n}_{total}$
Data Unit:	Count
Description:	Estimated total number of plots required.
Source of Data:	Calculated using equation [37] or equation [41].
Used in Equations:	[38], [42]
Frequency of monitoring/recording:	May be updated if a new sample with greater precision is desired at a monitoring period.
Comment:	

Data / Parameter:	o_i
Data Unit:	Binary
Description:	State observation for the i^{th} sample point
Source of Data:	Remote sensing image interpretation
Used in Equations:	[17]
Frequency of monitoring/recording:	Reevaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	$o_i^{[m]}$
Data Unit:	Proportion
Description:	State observation for the i^{th} sample point during monitoring period $[m]$
Source of Data:	Field observations
Used in Equations:	[33]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$\bar{o}^{[m]}$
Data Unit:	Proportion
Description:	Average of state observations taken in the leakage area for the during monitoring period $[m]$
Source of Data:	Field observations
Used in Equations:	[33]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	p_{forest}
Data Unit:	Proportion
Description:	The proportion of the project area that is forested.
Source of Data:	Determined at project validation using surveys and/or GIS analysis.
Used in Equations:	[33]
Frequency of monitoring/recording:	The proportion does not change after validation.
Comment:	

Data / Parameter:	$P(t_i)$
Data Unit:	Probability
Description:	Probability of making an observation at time t_i
Source of Data:	Equation [4]
Used in Equations:	[2]
Frequency of monitoring/recording:	Reevaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	$P(t_i, x_i, y_i)$
Data Unit:	Probability
Description:	Probability of observing a sample point in the reference area located at (x_i, y_i) at time t_i
Source of Data:	Equation [2]
Used in Equations:	
Frequency of monitoring/recording:	Reevaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	$P(x_i, y_i \mid t_i)$
Data Unit:	Probability
Description:	probability of observing location (x_i, y_i) given on observation is made at time t_i
Source of Data:	Equation [3]
Used in Equations:	[2]
Frequency of monitoring/recording:	Reevaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	p_{BGLT}
Data Unit:	Proportion
Description:	Proportion of below-ground large tree biomass removed as a result of land conversion to agriculture
Source of Data:	Selected by the project proponent based on guidance provided in section 6.6.4.
Used in Equations:	[24]
Frequency of monitoring/recording:	Held constant over the life of the project.
Comment:	

Data / Parameter:	$r_{BASE,i,j,k}$
Data Unit:	Meters
Description:	Base radius of the i^{th} tree in plot j in stratum k.
Source of Data:	Field measurements
Used in Equations:	[52]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	Half the diameter at breast height is recommended as an easily measured estimate of base radius for standing dead trees that is conservative in the project case. Actual measurements of base diameter can also be used.

Data / Parameter:	$\hat{r}_{LE}^{[m]}$
Data Unit:	Proportion
Description:	The estimated leakage factor as a proportion of baseline emissions
Source of Data:	Estimated based on the difference between observed deforestation in the reference area and predicted deforestation in the reference area as described in section 10.4.
Used in Equations:	[32]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	r_{sp}
Data Unit:	Unitless
Description:	Ratio of below-ground biomass to above-ground biomass (root to shoot ratio) for species sp.
Source of Data:	Peer reviewed literature relevant to the project area or IPCC GPG LULUCG Table 4.4.
Used in Equations:	[64], also see sections 13.6.1 and 13.6.2
Frequency of monitoring/recording:	Held constant throughout entire project lifetime.
Comment:	In equation [64], an average of non-tree species specific ratios, or a generic ratio that is appropriate for shrubs in the project area may be used.

Data / Parameter:	$r_{TOP,i,j,k}$
Data Unit:	Meters
Description:	Top radius of the i^{th} tree in plot j in stratum k
Source of Data:	Field measurements
Used in Equations:	[52]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	If accurate measurements of top radius (or diameter / 2) cannot be made, it is conservative to assume that the top radius is zero.

Data / Parameter:	r_{WP}
Data Unit:	Proportion
Description:	Proportion of above-ground large tree biomass converted to long-lived wood products
Source of Data:	Selected by the project proponent using guidance provided in section 6.6.10
Used in Equations:	[30]
Frequency of monitoring/recording:	Reevaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	t
Data Unit:	Time
Description:	Variable used to represent a point in time
Source of Data:	
Used in Equations:	[7], [11], [13], [21], [22], [23], [24], [25], [26], [27], [28], [29], [33]
Frequency of monitoring/recording:	
Comment:	

Data / Parameter:	t_0, t_1, t_2
Data Unit:	Time
Description:	t_0 = Time zero, the project start date t_1 = A point in time earlier than t_2 t_2 = A point in time later than t_1
Source of Data:	
Used in Equations:	[14], [18]
Frequency of monitoring/recording:	
Comment:	

Data / Parameter:	t_i
Data Unit:	Time
Description:	The time of the i^{th} sample point
Source of Data:	Remote sensing image interpretation
Used in Equations:	[1], [3], [5]
Frequency of monitoring/recording:	Reevaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	$U^{[m]}$
Data Unit:	Percent
Description:	Average uncertainty in carbon stocks and the baseline model
Source of Data:	Equation [36]
Used in Equations:	[35]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	U_{DF}
Data Unit:	Percent
Description:	Estimated uncertainty in the cumulative deforestation model
Source of Data:	Equation [15]
Used in Equations:	[36]
Frequency of monitoring/recording:	Reevaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	U_{SCL}
Data Unit:	Percent
Description:	Estimated uncertainty in the soil carbon loss model
Source of Data:	Equation [19]
Used in Equations:	[36]
Frequency of monitoring/recording:	Reevaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	$U_{TOTAL}^{[m]}$
Data Unit:	Percent
Description:	Estimated uncertainty of total carbon stocks
Source of Data:	Equation [67]
Used in Equations:	[36]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	$v_{i,j,k}$
Data Unit:	m^3
Description:	Volume of the i^{th} tree in plot j in stratum k.
Source of Data:	Equation [52]
Used in Equations:	[51]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	

Data / Parameter:	$v_{soil,j,k}$
Data Unit:	m^3
Description:	Total volume of soil sample in plot j in stratum k
Source of Data:	Field measurements
Used in Equations:	[60]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	

Data / Parameter:	$v_{rf,j,k}$
Data Unit:	m^3
Description:	Volume rock fragments (> 2mm) in soil sample taken in plot j in stratum k
Source of Data:	Field measurements
Used in Equations:	[60]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	

Data / Parameter:	w_i
Data Unit:	Unitless
Description:	The weight applied to the i^{th} sample point
Source of Data:	Equation [5]
Used in Equations:	[17]
Frequency of monitoring/recording:	Reevaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	$w_i^{[m]}$
Data Unit:	Unitless
Description:	The weight of the i^{th} sample point during monitoring period $[m]$
Source of Data:	Equation [5]
Used in Equations:	[33]
Frequency of monitoring/recording:	Updated at every monitoring period
Comment:	

Data / Parameter:	w_k
Data Unit:	Unitless
Description:	Proportion of plots allocated to stratum k.
Source of Data:	Calculated using equation [39] or [40].
Used in Equations:	[41], [42]
Frequency of monitoring/recording:	May be updated at each monitoring period.
Comment:	Intermediate variable used in estimating required sample size.

Data / Parameter:	$\boldsymbol{x}$
Data Unit:	Real, vector
Description:	Vector of observed covariates to deforestation
Source of Data:	Independent variable used in deforestation model. See equation [7] and section 6.4.7 for details.
Used in Equations:	[7]
Frequency of monitoring/recording:	Reevaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	$\boldsymbol{t}$
Data Unit:	Real, vector
Description:	Vector of observed times to forest state.
Source of Data:	Time variable used in deforestation model. See equation [7] and section 6.4.7 for details.
Used in Equations:	[7]
Frequency of monitoring/recording:	Reevaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	$\boldsymbol{w}$
Data Unit:	Real, vector
Description:	Vector of observation weights
Source of Data:	The initial vector of weights used when fitting the deforestation model using IRLS. See equation [7] and section 6.4.7 for details.
Used in Equations:	[7]
Frequency of monitoring/recording:	Reevaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	$\boldsymbol{o}$
Data Unit:	Real, vector
Description:	Vector of observed forest states
Source of Data:	The response variable used to fit the cumulative deforestation model using IRLS. See equation [7] and section 6.4.7 for details.
Used in Equations:	[7]
Frequency of monitoring/recording:	Reevaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	x_i
Data Unit:	Varies
Description:	The latitude of the i^{th} sample point
Source of Data:	Remote sensing image interpretation
Used in Equations:	[1] , [3], [5]
Frequency of monitoring/recording:	Reevaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	$x_{i,j,k}$
Data Unit:	Varies
Description:	i^{th} measurement in plot j in stratum k
Source of Data:	Field measurements
Used in Equations:	[45]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	This is a generic variable. For example, it may represent the diameter of the i^{th} tree in plot j in stratum k.

Data / Parameter:	$x_{i,j,k,d}$
Data Unit:	m
Description:	Diameter of i^{th} piece of lying dead wood on transect j in stratum k, decay class d
Source of Data:	Field measurements.
Used in Equations:	[58]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	Note that diameter must be expressed in meters for estimating the volume of lying dead wood.

Data / Parameter:	y
Data Unit:	Varies
Description:	y is a placeholder variable. It is used to represent plot level carbon stocks as well as transformed variables in a regression context.
Source of Data:	As described for each equation.
Used in Equations:	[12]
Frequency of monitoring/recording:	
Comment:	

Data / Parameter:	y_i
Data Unit:	Longitude
Description:	The longitude of the i^{th} sample point
Source of Data:	Remote sensing image interpretation
Used in Equations:	[1], [3], [5]
Frequency of monitoring/recording:	Re-evaluated whenever the baseline model is re-assessed.
Comment:	

Data / Parameter:	$y_{INTACT,j,k}$
Data Unit:	Tonnes CO2e per hectare
Description:	Carbon stock in standing dead trees in decay class I, plot j, stratum k
Source of Data:	Field measurements
Used in Equations:	[66]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	

Data / Parameter:	$y_{DECAYED,j,k}$
Data Unit:	Tonnes CO2e per hectare
Description:	Carbon stock in standing dead trees in decay class II, plot j, stratum k
Source of Data:	Field measurements
Used in Equations:	[66]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	

Data / Parameter:	$y_{j,k}$
Data Unit:	Varies
Description:	Attribute of plot j, stratum k
Source of Data:	Field measurements
Used in Equations:	[44], [46], [56], [57]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	This is a generic variable. For example, it may represent the total carbon stock per unit area in standing dead wood in plot j, stratum k.

Data / Parameter:	y_k
Data Unit:	Varies
Description:	Attribute of stratum k
Source of Data:	Field measurements
Used in Equations:	[59]
Frequency of monitoring/recording:	Updated at each monitoring period.
Comment:	This is a generic variable. For example, it may represent the average carbon stock per unit area in lying dead wood in stratum k.

DOCUMENT HISTORY

Version	Date	Comment
v1.0	11 Feb 2011	Initial version released
v1.1	10 Nov 2011	Clarifications were made to the soil carbon loss model in section 6.5. Specifically, updates (all effective on issue date) were made to: 1. Clarify the lambda value in section 6.5.2 2. Clarify the procedures for soil sampling in section 6.5.3.