VCS MODULE VMD0022

ESTIMATION OF CARBON STOCKS IN LIVING PLANT BIOMASS

Version 1.0

16 November 2012

Sectoral Scope 14

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1 SOURCES

Adapted from CDM AR-AM0001 (now in consolidated methodology CDM AR-ACM0002), CDM AR-AM0004 Reforestation or afforestation of land currently under agricultural use.

CDM A/R Methodological Tool *Calculation of the number of sample plots for measurements within A/R CDM project activities* (Version 02)

2 SUMMARY DESCRIPTION OF THE MODULE

This module provides the methods to be used to estimate the required number of living plant biomass plots in each stratum, design and establish the plots, and check the statistical rigor of the results.

3 DEFINITIONS

Biomass Expansion Factor (BEF):	The ratio of the total aboveground *biomass* to the measured portion of the biomass of a plant
Ex-ante:	Before the fact. Projection of values or conditions in the future.
Ex-post:	After the fact. Estimation of values or conditions in the present or past.
Permanent Sample Plots:	Plot being measured more than once and provide high quality, long-term, local data on growth of the existing forest for a variety of species and sites.
Project Area:	The area of land on which the project proponent will undertake project activities.
Significant:	A pool or source is significant if it does not meet the criteria for being deemed de minimis. Specific carbon pools and GHG sources, including carbon pools and GHG sources that cause project and leakage emissions, may be deemed de minimis and do not have to be accounted for if together the omitted decrease in carbon stocks (in carbon pools) or increase in GHG emissions (from GHG sources) amounts to less than five percent of the total GHG benefit generated by the project.
Stratum (plural strata):	An area of land within which the value of a variable, and the processes leading to change in that variable, are relatively homogenous.
Woody Biomass:	Biomass which exists primarily in the form of lignified tissues, such as that of shrubs and trees. Typically accounting of woody biomass includes the non woody parts (leaves, etc.) of plants which contain woody biomass.
Wood Density:	The mass per unit volume of the dry wood of a given species.

4 APPLICABILITY CONDITIONS

None

5 PROCEDURES

Introduction

Living vegetation may be found in a wide number of forms and distributions, including woody and non-woody, and evenly distributed, clumped, or scattered. A number of different techniques may be used to sample living vegetation, depending on the nature of the type and distribution. This module provides methods for three separate but related approaches to determining total living plant biomass in a stratum. Several basic variables are determined through sampling:

For trees and large woody vegetation

- The number of trees per stratum by species or species group.
- The size of the trees.

For small woody vegetation and non-woody vegetation

- The amount of aboveground biomass in a specified area.

Based on these variables, total biomass will be estimated.

Separate approaches are therefore given for sampling and calculation of biomass for trees and large woody vegetation, and for small woody and non-woody vegetation.

PART A: Trees and large woody vegetation

Step 1: Stratification and determination of distribution

Stratification of the area within the project area, and where required within the leakage belt or reference region, must be undertaken using the methods specified in module *VMD0018 Methods to Determine Stratification*. During stratification, particular attention should be given to the species and spatial distribution, and ecological and management dynamics of the trees and large woody species.

Step 2: Determination of the number, size and distribution of woody species.

Based on the preliminary stratification, one of three basic approaches must be used to estimate the number and size of large woody species individuals:

1) ***Census from remote sensing, plus correlation with ground sampling***

   Determining the number of individuals

   This approach is particularly suited to sampling woody individuals where those individuals are openly distributed, or scattered, and where the individuals are mostly large enough to be detected using remote sensing and automated classification techniques. This approach has the advantage of allowing a complete (100%) census, or estimation based on censusing of large portions of an area, to determine the number of individuals present. This approach is also particularly suitable where remote sensing techniques based on historical images will be used in module *VMD0025 Estimation of Woody Biomass Harvesting and Utilization* to forecast future trajectories of woody species populations.

Conducting a census from remote sensing typically requires the use of high resolution satellite based images (Quickbird or similar), or, preferably, aerial systems providing sub-meter resolution.

Automated techniques to identify woody species individuals and quantify the number of individuals present can be implemented using a number of remote sensing and GIS software packages. Specific packages are not identified in this methodology, since this is a rapidly developing field. However, the software package chosen must have been subject to peer review for uses similar to those being applied in the project, and must be recognized as a leading software package for this purpose (For example: ECognition, ArcGIS). Depending on the nature of the data, and the species present on the site, it may also be possible to determine the species mix from the remote sensing data. Where this is not possible, the species mix must be determined using ground sampling.

Where remote sensing techniques are used, but a 100% census is not undertaken, selection of areas to assess must be systematic and unbiased.

For QA/QC purposes, error estimations of interpretations of remote sensing images must be made using other data – ideally ground sampling. Ground sampling must be undertaken such that trees identified from remote sensing data can be located on the ground, and errors detected, such as:

- Trees which have been missed in the interpretation of the remote sensing data.
- Trees which have been identified in the remote sensing data, but which do not exist on the ground – for instance, erroneous interpretation of shadow areas as trees.
- Trees identified from the remote sensing data which are actually tree clumps on the ground.

The maximum allowable error (difference between the number of trees detected from remote sensing and the actual number found on the ground) must not exceed 10%.

In some cases, remote sensing may be efficient to detect individuals over a certain size, but may miss smaller individuals. In such a case, ground sampling methods must be used to inventory the smaller woody individuals, and a check between ground samples and remote census must be undertaken to ensure that neither systematic double counting nor systematic failure to detect individuals of a given size class is occurring.

Determining the size and species of individuals

Where remote sensing techniques are used to determine the number of individuals, one of the following two techniques must be used to determine the size and species of individuals:

a. Correlation to detectable canopy size classes and spectral signatures.

   Where remote sensing imagery has high enough resolution to permit automated classification of canopy size and spectral signatures for individuals of woody species, it may be possible to determine a function which relates canopy size and detected species to biomass in individuals. Developing such a function requires the following steps:

1. Division of the detectable canopy sizes into canopy size classes. The number of classes will depend on the size variation of individuals in the woody species layer, and the resolution of the imagery, but a maximum of five or six classes must be defined. The goal of identifying canopy size classes is to reduce the variance, and therefore the number of samples required to achieve acceptable statistical significance in correlating canopy size to biomass. Selection of both detectable canopy size classes, as well as spectral signatures, as discussed in the step below, must be undertaken using existing peer reviewed industry standard methods. Specific details are not given here, as this is a rapidly changing field.
2. Determination of the spectral signatures for individual species or groups of similar species. Note that the ground sampling undertaken in the next step may determine that the correlation between canopy size and biomass extends across multiple species, or may in some cases apply with acceptable accuracy across all trees present on the site. Thus the final analysis may be able to lump species together even though those species are identifiable using their spectral signature.
3. Ground sampling of specific individuals, identifiable from the remote sensing, and covering the range of identifiable canopy size classes, and identified species. Note that in this case establishment of plots containing more than 1 tree is not required, since numbers are determined from the remote sensing, and ground sampling is for determination of biomass and species identification only.
4. Calculation of above and below ground biomass for each sampled individual, using one of the techniques given in Step 3 below.
5. Analysis of statistical variance in the biomass of the sampled individuals in each canopy size class. In general the error of the mean must be not more than +/- 10% at a 90% confidence level.
6. If good statistical correlation based on the analysis of statistical variance is found between canopy size class and biomass, a function can be developed, and woody species biomass can be calculated from the remote sensing images.

Using this technique, biomass will be calculated using the following equation:

$$B_{ws} = bws + (\sum_{sg}^{y}(\sum_{c}^{x}(t\#_{sc} \cdot bw_{sc}))) \cdot A_s \cdot A_c^{-1} \quad (6.1)$$

Where:

B_{ws}	=	Total large woody biomass in stratum s, tonnes
bws	=	Total woody biomass in the stratum of individuals too small to detect by remote sensing, calculated using the techniques given in section 3 below, tonnes
sg	=	The species or species groups
y	=	The number of species or species groups

c	=	The canopy size classes, non-dimensional
x	=	The number of canopy size classes
$t\#_{sc}$	=	The number of individuals of a given species or species group and a given canopy size class in the *stratum*, non-dimensional
bw_{sc}	=	The average woody biomass per individual in a given canopy size class and species or species group
A_s	=	The area of the stratum
A_c	=	The area of the portion of the stratum which was censused using remote sensing

As noted above, the woody species layer may also contain some individuals below a cut-off for detection by remote sensing. Biomass for these size classes will be estimated using the plot methods given below.

While this approach may require substantial sampling effort to achieve the required statistical relevance, it has the advantage of allowing direct estimation of woody species biomass from historical images. This may significantly aid in the development of woody species biomass projections for use in estimation of long lived wood products where relevant.

b. Without canopy size class detection

Where reliable correlations (measured using statistical variance of the samples taken within the canopy size class, as discussed in Step 2.1.a.1) between canopy size class and biomass are not expected or where canopy size cannot be reliably detected from remote sensing, the same techniques as those given above must be used, except that only one canopy size class, encompassing all detectable individuals, will be used. In this case a large number of individuals may need to be sampled to reach the required statistical precision, since individuals of all sizes will be sampled.

2) Area from remote sensing, plus sampling

This approach uses remote sensing to identify areas of woody species, combined with ground sampling to determine the woody species density within those areas. It is particularly suited to clumpy distributions of woody species, where the clumps are too frequent to be efficiently stratified out as a separate stratum.

In this case remote sensing resources are used to delineate in a GIS the areas covered in woody species, and ground sampling is then undertaken to determine the density and biomass of individuals within these areas, using the ground sampling methods discussed below, but with sampling confined to the areas identified from the remote sensing.

3) Ground Sampling

Ground sampling is the most commonly used approach to estimating the number, species and size of trees present in an area. Ground sampling is preferred for high density woody species stands, whether continuous or clumped, and for areas dominated by shrubs and small trees which are difficult to detect remotely.

When ground based sampling is used for sampling of woody biomass, permanent sampling plots should be used for sampling over time to measure and monitor above and below ground biomass. Permanent sample plots are generally regarded as statistically efficient in estimating changes in forest biomass and carbon stocks because there is typically a high covariance between observations at successive sampling events. However, the project proponent must ensure that the plots are treated in the same way as other lands within the project area (e.g., during site and soil preparation, weeding, fertilization, irrigation, or thinning). Ideally, staff involved in management activities should not be aware of the location of monitoring plots. Where local markers are used, these should not be visible.

Plots must be established using the following guidance:

Plot size and shape

- Trees: Plot size and design for the measurement of trees will vary depending on the nature of the stand. If consisting of multiple age or size classes of trees, with different distributions for each class, nested plots may be used. For single age stands, a single plot size should be sufficient. The size of plots depends on the density of trees, in general between 100 m^2 for dense stands and 1000 m^2 for open stands. However, larger plots capturing more trees may be more efficient in cases where access is difficult and variability high, since fewer plots may be required.
- Non-tree woody vegetation: Plot area for larger non-tree woody vegetation will also depend on the distribution of the non-tree vegetation. For relatively dense, uniform layers, a plot as small as 4 m^2 may be used. For strata with growing trees, the plots should be sub-plots of plots for measuring trees;
- Plots may be any shape, as long as shape is predetermined to avoid bias, and the plot boundaries can be reliably relocated for subsequent re-measurement. In general, for smaller plots circular plots are often more efficient, while for larger plots square or rectangular plots are preferred.

Number of Plots

The number of plots depends on species, density and size variability within the stratum, accuracy requirements and monitoring interval. In this methodology the total sum of samples and the sample size is determined using the approved CDM A/R Methodological Tool *Calculation of the number of sample plots for measurements within A/R CDM project activities* (AR-AM Tool 03 - Version 02 or later version).

It is possible to reasonably modify the sample size after the first monitoring event based on the actual variation of the carbon stock changes found.

Plot Location

To avoid subjective choice of plot locations (plot centers, plot reference points, movement of plot centers to more "convenient" positions), the permanent sample plots must be located either systematically with a random start, or randomly using a randomization algorithm in a GIS system. Location of plots can be accomplished with the help of a GPS in the field. The geographical position (GPS coordinate), administrative location, stratum and sub-stratum series number of each plots must be recorded and archived.

Sampling plots should be as proportionally distributed across geographic sites as possible For example, if one *stratum* consists of three geographically separated sites, then the project proponent could:

- Divide the total stratum area by the number of plots, resulting in the average area per plot;
- Divide the area of each site by this average area per plot, and assign the integer part of the result to this site. For example, if the division results in 6.3 plots, then 6 plots are assigned to this site and 0.3 plots are carried over to the next site, and so on.

Step 3: Calculation of biomass – Trees

The amount of aboveground biomass and belowground biomass in each measured tree can be estimated using either of two methods, the Allometric Equations method or the Biomass Expansion Factors (BEF) method.

Allometric method

Step a: Measure the diameter at breast height (DBH, at 1.3 m above ground), and preferably the height, of all the trees in the permanent sample plots above a minimum DBH. The minimum DBH varies depending on tree species and climate, for instance, the minimum DBH may be as small as 2.5 cm in arid environments where trees grow slowly, whereas it could be up to 10 cm for humid environments where trees grow rapidly (GPG-LULUCF, 2003).

When first measured all trees must be tagged to permit the tracking of individual trees in plots through time.

Step b: Choosing or establishing and applying appropriate allometric equations.

$$B_{ABs} = f(DBH, H) \tag{6.2}$$

Where:

B_{ABs}	=	Aboveground biomass of tree in stratum s, tonnes tree^{-1}
$f_i(DBH,H)$	=	An allometric equation linking aboveground biomass (tonnes tree^{-1}) to diameter at breast height (DBH) and possibly tree height (H).

Allometric equations produce estimates of biomass in kg per tree.

Preferably, the allometric equations used are locally-derived, species-specific, and peer reviewed.

When such Allometric equations are not available, Allometric equations developed from a biome-wide database, such as those in Annex 4.A.2, Tables 4.A.1 and 4.A.2 of GPG LULUCF (2003), may be used. Where such equations are used, project proponents must verify the equation's applicability to the project. Verification must be undertaken by destructively harvesting no less than 5 trees of the species or species group to which the equation is to be applied within the *project area* but outside the sample plots. The biomass of these trees must be measured, and compared to the results derived from the selected equation. If the biomass measured from the harvested trees is not more than 10% less than that predicted by the Allometric equation, it can be assumed the selected equation is suitable for the project.

If this is not the case, it is recommended to develop local allometric equations for the project. In order to develop the equations, a sample of trees, representing different size classes, is destructively harvested, and the total dry biomass of each tree is determined. The number of trees to be destructively harvested and measured depends on the range of size classes and number of species—the greater the heterogeneity the more trees are required. Finally, allometric equations are constructed relating the biomass with values from easily measured variables, such as the DBH and total height (see Chapter 4.3 in GPG LULUCF (2003)).

Step c: Estimate belowground biomass using root to-shoot ratios and aboveground carbon stock.

$$B_{BBs} = B_{ABs} \cdot R \tag{6.3}$$

Where:

B_{BBs} = Belowground biomass of tree in stratum s, tonnes

B_{ABs} = Aboveground biomass of tree in stratum s, tonnes

R = Root-to-shoot ratio

Note that in some cases the allometric equations utilized in step b may provide direct estimates of both above and below ground biomass, in which case Step c will be unnecessary. Where a root-to-shoot ratio is used, it must be selected based on the same criteria as those discussed in step C of the BEF method, below.

BEF Method

Step a: Measure the diameter at breast height (DBH, at 1.3 m above ground), and preferably the height, of all the trees in the permanent sample plots above a minimum DBH. The minimum DBH varies depending on tree species and climate, for instance, the minimum DBH may be as small as 2.5 cm in arid environments where trees grow slowly, whereas it could be up to 10 cm for humid environments where trees grow rapidly (GPG-LULUCF, 2003).

Step b: Estimate the volume of the commercial component of trees based on locally derived equations. It is also possible to combine step a above and this step if field instruments are used (e.g. relascope) that measure volume of each tree directly.

Step c: Choosing BEF and root-to-shoot ratio: The BEF and root-to-shoot ratio vary with local environmental conditions, species and age of trees, and the volume of the commercial component of trees. These parameters can be determined by either developing a local regression equation or selecting from national inventory, Annex 3A.1 Table 3A.1.10 of GPG LULUCF (2003), or from published sources. If a significant amount of effort is required to develop local BEFs and root-to-shoot ratio, involving, for instance, harvest of trees, then it is recommended not to use this method but rather to use the resources to develop local Allometric equations as described in the Allometric method above (refers to Chapter 4.3 in GPG LULUCF, 2003). If that is not possible either, national species specific defaults for BEF and R can be used. Since both BEF and the root-to-shoot ratio are age dependent, it is desirable to use age-dependent equations. Stem wood volume can be very small in young stands and BEF can be very large, while for old stands BEF is usually significantly smaller. Therefore using average BEF value may result in significant errors for both young stands and old stands. It is preferable to use allometric equations, if the equations are available, and as a second best solution, to use age-dependent BEFs (but for very young trees, multiplying a small number for stem wood with a large number for the BEF can result in significant error).

Step d: Converting the volume of the commercial component of trees into aboveground biomass and belowground biomass via basic wood density, BEF, root-to-shoot ratio and carbon fraction, given by[1]:

$$B_{AB_s} = V \cdot D \cdot BEF \tag{6.4}$$

$$B_{BB_s} = B_{AB_s} \cdot R \tag{6.5}$$

Where:

B_{ABs}	=	Aboveground biomass, tonnes
B_{BBs}	=	Belowground biomass, tonnes
V	=	Merchantable volume, m^3
D	=	Wood density of the species, in dry weight per unit volume, tonnes d.m.m^{-3} merchantable volume.
BEF	=	*Biomass* expansion factor for conversion of biomass of merchantable volume to aboveground biomass, dimensionless.
R	=	Root-to-shoot ratio, dimensionless

Step 4: Calculation of total woody biomass per plot

Total tree biomass per plot is the sum of all above and below ground biomass in all trees within the plot. Where nested plots or plots of different sizes for different types of woody biomass have been used, each different plot size must be calculated separately.

Step 5: Testing statistical confidence

Calculations to test the statistical confidence of the mean must be carried out on the total above and below ground large woody biomass per plot for each stratum. As described above, where nested or different sized plots are used, separate calculations must be done for each size or type of plot, or statistical calculations may be carried out on a per unit area basis (usually by conversion of individual plot results to per ha results prior to statistical analysis). Confidence interval must not be greater than 10%, at a 90% confidence level, for each stratum.

Where the confidence interval exceeds +/- 10% with 90% confidence, project proponents may undertake one of three actions:

[1] Refers to GPG LULUCF Equation 4.3.1

a. Re-stratify: Where the variance in the samples appears to be correlated to geographic or other factors, re-*stratification* can be considered, as discussed in module *VMD0018 Methods to Determine Stratification*. If re-stratification is undertaken, confidence intervals must be re-calculated for the new *strata*. Re-stratification will require the installation of further randomly or systematically located plots if the confidence interval in one of the new strata fails to meet the required confidence standards unless option C is chosen for that stratum.

b. Increase the number of plots: Where the variance appears to be inherent to and distributed across the stratum, the project proponent may choose to install further plots. An estimate of the required number of further plots should be calculated, using the equation below (3), and further plots installed, located systematically or randomly.

$$N = t^2 \cdot s^2 \cdot (0.1 \cdot m)^{-2} \qquad (6.6)$$

Where

N	=	Total number of plots expected to be required
t	=	Student t-test 0.90 value for n-1, n being the number of plots already established
s	=	Standard deviation for the existing plot values
m	=	Mean value of the variable from the existing plots

c. Recalculate B_{ws}

In some cases, due to project size or other factors, installing enough plots to meet the required confidence interval may not be economically viable. In these cases, and provided that project proponents install a minimum of 10 plots per stratum, project proponents may proceed with data gathered to a lower confidence interval. However, project proponents must recalculate B_{wi} (from step 6 below) as follows:

1. Where sampling is undertaken prior to project commencement to determine the baseline

$$B_{ws} = B_{ws} \bullet (1 + (ci - 0.1)) \qquad (6.7)$$

Where:

B_{ws}	=	Total large woody biomass in stratum s, tonnes
ci	=	The calculated confidence interval at 90% confidence

2. Where sampling is undertaken after project commencement to determine biomass carbon under the project scenario

$$B_{ws} = B_{ws} \bullet (1 - (ci - 0.1)) \qquad (6.8)$$

Where

B_{ws}	=	Total large woody biomass in stratum s, tonnes

ci = The calculated confidence interval at 90% confidence

Step 6: Calculation of total large woody biomass

The total large woody biomass for each stratum is calculated using the following equation:

$$B_{ws} = A_s \cdot \sum_{p}^{z} (B_{wp} \cdot 10^4 \cdot s_p^{-1}) \tag{6.9}$$

Where:

B_{ws} = Total large woody biomass in stratum s, tonnes

A_s = The area of the stratum s, hectares

p = The different plot sizes or types

z = The number of plot sizes or types

B_{wp} = The average woody biomass per plot in a given plot size or type p, tonnes

s_p = The size of the given plot type p, m^2

PART B: Small woody and non-woody vegetation

For smaller woody and non-woody vegetation a destructive sampling method must be used. The steps in sampling and calculating biomass for smaller woody and non woody biomass are:

Step 1: Stratification and determination of distribution

Stratification of the area within the project area, and where required within the leakage belt or reference region, must be undertaken using the methods given in module *VMD0018 Methods to Determine Stratification*. During stratification, particular attention must be given to the species and spatial distribution, and ecological and management dynamics of the smaller woody and non-woody vegetation.

Step 2: Sampling

Step a: **Plot Size**. Destructive sampling entails the collection of all aboveground material within the plot. As such, plots are typically relatively small, to avoid the necessity of collecting large amounts of material. Square plots of 1m by 1m are acceptable where the material is relatively evenly distributed at the individual plant level. Where more heterogeneous distributions are found, larger plots may be considered.

Step b: Plot Location. Plots must be systematically or randomly distributed throughout the *stratum*. Where large woody plants and trees are also being sampled using the methods given above, plots must be located in areas where remote sensing or ground sampling allows the individual trees and large shrubs to be clearly identified and excluded from the destructive sampling, to ensure that double counting, or missing of some biomass, does not occur. Where destructive sampling is being undertaken in combination with permanent sample plots, the location of the destructive sampling sub-plot within the permanent sample plot must be recorded, and a new location for the destructive sampling subplot must be chosen for each subsequent re-measurement of the permanent sample plot.

Where a significant proportion of the small woody and non-woody material being sampled is distributed in clumps or patches, notes must be taken identifying whether the plot falls in a clump or patch or in an area between clumps or patches. If the area is highly heterogeneous due to clumpiness, it may be necessary to summarize the results separately for the clumps and the areas between the clumps, in order to reduce the number of plots required to meet statistical precision levels.

If plots within clumps and outside clumps are summarized separately, the amount of area within a stratum consisting of clumps or patches must be determined. This may be done in one of two ways:

- From remote sensing, if the clumps or patches are clearly identifiable on remote sensing images.
- Using a line intersect survey. A line intersect survey consists of lines systematically laid out and covering the stratum evenly and without bias. Each line is walked, and notes are kept on the sections of the line which fall within clumps or patches. The percentage of the total line length falling within a clump or patch is then the estimated percentage of the area lying in clumps or patches.

Step c: Installation of plots and measurement of biomass. Within the designated plot area, all biomass which has not been accounted in a survey of trees and large woody biomass is cut and collected. This biomass is then weighed, oven dried, and weighed again, to give both green and dry weights. Ideally the biomass is oven dried, to achieve “bone dry” conditions. However, drying in direct sun may also be used. In case biomass samples are weighed after sun drying, small representative subsamples need to be taken from the larger sample, weighed, oven dried as described above, and weighed again to determine the level of residual moisture in the weighed sample. The dry weights of the samples must then be adjusted accordingly, to provide an estimated oven dry weight of the biomass per plot.

Step 3: Testing statistical confidence

Calculations to test the statistical confidence of the mean must be carried out on the total above ground biomass per plot. The error of the mean must not be greater than 10%, at a 90% confidence level.

Where the confidence interval exceeds +/- 10% with 90% confidence, project proponents may undertake one of three actions:

a. Re-stratify: Where the variance in the samples appears to be correlated to geographic or other factors, re-stratification should be considered, as discussed in module *VMD0018 Methods to Determine Stratification*. If re-stratification is undertaken, confidence intervals must be re-calculated for the new strata. Re-stratification will require the installation of further randomly or systematically located plots if the confidence interval in one of the new strata fails to meet the required confidence standards, unless option c is chosen for that stratum.

b. Increase the number of plots: Where the variance appears to be inherent to and distributed across the stratum, the project proponent may choose to install further plots. An estimate of the required number of further plots must be calculated, using the equation below (3), and further plots installed, located systematically or randomly.

$$N = t^2 \cdot s^2 \cdot (0.1 \cdot m)^{-2} \quad (6.10)$$

Where

N = Total number of plots expected to be required

t = Student t-test 0.90 value for n-1, n being the number of plots already established

s = Standard deviation for the existing plot values

m = Mean value of the variable from the existing plots

c. Recalculate B_{sms}
In some cases, due to project size or other factors, installing enough plots to meet the required confidence interval may not be economically viable. In these cases, and provided that project proponents install a minimum of 10 plots per stratum, project proponents may proceed with data gathered to a lower confidence interval. However, project proponents must recalculate B_{smi} (from step 4 below) as follows:

i. Where sampling is undertaken prior to project commencement to determine the baseline

$$B_{sms} = B_{sms} \bullet (1 + (ci - 0.1)) \quad (6.11)$$

Where:
B_{sms} = Total biomass of small woody and non-woody living vegetation in *stratum* s, t

ci = The calculated confidence interval at 90% confidence

ii. Where sampling is undertaken after project commencement to determine biomass carbon under the project scenario

$$B_{sms} = B_{sms} \bullet (1 - (ci - 0.1)) \quad (6.12)$$

Where
B_{sms}= Total biomass of small woody and non-woody living vegetation in *stratum* s, t

ci = The calculated confidence interval at 90% confidence

Step 4: Calculation of Total Small Woody and Non-woody Biomass

Total small woody and non-woody biomass per stratum is then calculated using the following equation:

$$B_{sms} = (\sum_{sbp}^{w} b_s) \cdot 10^2 \cdot A_{sbp}^{-1} \cdot A_s \cdot (1 + R_s) \quad (6.13)$$

Where:

B_{sms}	=	Total biomass of small woody and non-woody living vegetation in *stratum* s, t
sbp	=	Small biomass plots
w	=	Number of small biomass plots
b_s	=	Biomass of the collected small woody and non-woody vegetation in each plot, kg
A_{sbp}	=	Area of the small biomass plot, m2
A_s	=	The area of the stratum, hectares
R_s	=	A root-to-shoot ratio for the small woody and non-woody biomass, Dimensionless

Notes:

1) Where distribution of biomass has been clumpy or patchy, it may be necessary to undertake the calculation twice, once for the clumps or patches, and once for the areas between the clumps or patches, and then to sum the results. In this case, the area *A* will be the area of the patches, or the area between the patches, as relevant.
2) Determination of the root-to-shoot ratio R_s for highly heterogeneous species mixes may be complex. Where different species sampled have different root-to-shoot ratios, the most conservative (smallest) root-to-shoot ratio must be used for the calculations. In many cases, root-to-shoot ratios can be found in the scientific literature. However, consideration should also be given to undertaking excavation and weighing of dry root and top weight for species where good root-to-shoot ratios are not found in the literature[2], and where the proponent has reason to believe that the species in question may vary significantly from other species. Since undertaking this measurement may be extremely difficult, the proponent may alternately propose a root-to-shoot ratio for the species which is demonstrably conservative (for instance, which is lower than the known root-to-shoot ratio for the most comparable species).

PART C: Total Living Biomass

Total living biomass in a stratum is the sum of the tree and large woody biomass, as calculated in Part A, and the small woody and non-woody biomass, as calculated in Part B:

$$B_s = B_{ws} + B_{sms} \quad (6.14)$$

Where:

B_s	=	Total biomass in stratum s, t
B_{ws}	=	Total large woody biomass, t
B_{sms}	=	Total biomass of small woody and non-woody living vegetation, t

[2] Example Table 3A.1.8 in GPG LULUCF 2000 (http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/Chp3/Anx_3A_1_Data_Tables.pdf), or **P.E.** Levy [*], S.E. Hale and B.C. Nicoll, 2004, Forestry, 77 (5): 421-430, Biomass expansion factors and root : shoot ratios for coniferous tree species in Great Britain.

6 PARAMETERS

Data Unit / Parameter:	bw_{sc}
Data unit:	Tonnes
Description:	The average woody biomass per individual per species in a given canopy size class
Source of data:	Estimation from ground sampling
Justification of choice of data or description of measurement methods and procedures applied:	Single tree sampling of individuals identified and randomly chosen from remote sensing, using standard field mensuration methods given in the methodology
Any comment:	

Data Unit / Parameter:	C
Data unit:	Dimensionless
Description:	Canopy size classes
Source of data:	Remote sensing imagery
Justification of choice of data or description of measurement methods and procedures applied:	Determined by dividing the range of canopy sizes detectable from remote sensing imagery into groupings based on the distribution of canopy sizes found.
Any comment:	

Data Unit / Parameter:	X
Data unit:	#
Description:	The number of canopy size classes
Source of data:	Remote sensing imagery
Justification of choice of data or description of measurement methods and procedures applied:	The number of canopy size classes c determined using the methods described for that variable
Any comment:	

Data Unit / Parameter:	*Sg*
Data unit:	Dimensionless
Description:	The individual tree species or species groups
Source of data:	Determined by the proponent based on techniques described below.
Justification of choice of data or description of measurement methods and procedures applied:	Combination of remote sensing and ground surveys to identify species or species groups which are distinguishable in remote sensed imagery using spectral signature, form, etc.
Any comment:	

Data Unit / Parameter:	*Y*
Data unit:	#
Description:	The number of species or species groups distinguished
Source of data:	Remote sensing and ground truthing
Justification of choice of data or description of measurement methods and procedures applied:	The number of canopy size classes *s* determined using the methods described for that variable
Any comment:	

Data Unit / Parameter:	$t\#_{sc}$
Data unit:	Dimensionless
Description:	The number of individuals of a given species or species group and a given canopy size class in the stratum, no dimension
Source of data:	Remote sensing imagery
Justification of choice of data or description of measurement methods and procedures applied:	Count of individuals from remote sensing imagery
Any comment:	

Data Unit / Parameter:	*Bws*
Data unit:	*T*onnes
Description:	Total woody biomass in the stratum of individuals too small to detect by remote sensing,
Source of data:	Estimated using field surveys
Justification of choice of data or description of measurement methods and procedures applied:	Calculated using the techniques given in section C of this methodology
Any comment:	

Data Unit / Parameter:	B_{ws}
Data unit:	*T*
Description:	Total large woody biomass per stratum
Source of data:	Calculated
Justification of choice of data or description of measurement methods and procedures applied:	Calculated using equation 6.1
Any comment:	

Data Unit / Parameter:	A_s
Data unit:	Hectares
Description:	Area of the stratum
Source of data:	Measured
Justification of choice of data or description of measurement methods and procedures applied:	Measured from ground surveys or cartography
Any comment:	

Data Unit / Parameter:	A_c
Data unit:	m^2
Description:	Area of the portion of the stratum censused
Source of data:	Measured
Justification of choice of data or description of measurement methods and procedures applied:	Measured from cartography
Any comment:	

Data Unit / Parameter:	B_{ABs}
Data unit:	tonnes tree^{-1}
Description:	Aboveground biomass of tree in stratum s
Source of data:	Calculated
Justification of choice of data or description of measurement methods and procedures applied:	Calculated using an allometric equation linking a measurable (usually diameter breast height) to total tree biomass
Any comment:	

Data Unit / Parameter:	B_{BBs}
Data unit:	Tonnes
Description:	Belowground biomass of tree in stratum s
Source of data:	Calculated
Justification of choice of data or description of measurement methods and procedures applied:	Calculated using a root-to-shoot ratio
Any comment:	

Data Unit / Parameter:	R
Data unit:	Dimensionless
Description:	Root-to-shoot ratio for the given species or species group and size/age class
Source of data:	Existing data or measurement
Justification of choice of data or description of measurement methods and procedures applied:	Derived from existing data where appropriate data exists. In some cases some destructive sampling may be required to determine this ratio.
Any comment:	

Data Unit / Parameter:	V
Data unit:	m^3
Description:	Merchantable volume
Source of data:	Calculated
Justification of choice of data or description of measurement methods and procedures applied:	Calculated from field measurements
Any comment:	

Data Unit / Parameter:	*D*
Data unit:	Tonnes d.m.m^{-3} merchantable volume.
Description:	Wood density for the species
Source of data:	Existing data
Justification of choice of data or description of measurement methods and procedures applied:	Derived from existing data for wood density of the species. Preferably from local research.
Any comment:	

Data Unit / Parameter:	*BEF*
Data unit:	Dimensionless
Description:	Biomass expansion factor applicable to the species or species group
Source of data:	Existing research or destructive sampling
Justification of choice of data or description of measurement methods and procedures applied:	These parameters can be determined by either developing a local regression equation or selecting from national inventory, Annex 3A.1 Table 3A.1.10 of GPG LULUCF, or from published sources.
Any comment:	

Data Unit / Parameter:	*P*
Data unit:	#
Description:	The different plot sizes or types
Source of data:	Field survey
Justification of choice of data or description of measurement methods and procedures applied:	The different plot sizes or types used to measure biomass of different size classes, determined by the proponent to meet statistical requirements
Any comment:	

Data Unit / Parameter:	*Z*
Data unit:	#
Description:	The number of plot sizes or types *p*
Source of data:	Field survey
Justification of choice of data or description of measurement methods and procedures applied:	Count of the number of plot sizes or types used for large woody vegetation
Any comment:	

Data Unit / Parameter:	B_{wi}
Data unit:	*Tonnes*
Description:	The average woody biomass per plot in a given plot size or type i
Source of data:	Plot measurements
Justification of choice of data or description of measurement methods and procedures applied:	Estimation from plot measurements using methods given in the methodology
Any comment:	

Data Unit / Parameter:	s_p
Data unit:	m^2
Description:	The size of the given plot type p
Source of data:	Field survey
Justification of choice of data or description of measurement methods and procedures applied:	The size of the different plot sizes or types used to measure biomass of different size classes is determined by the proponent to meet statistical requirements
Any comment:	

Data Unit / Parameter:	B_{sms}
Data unit:	*T*
Description:	Estimated total biomass of small woody and non-woody living vegetation in stratum s
Source of data:	Calculated estimate from field sampling
Justification of choice of data or description of measurement methods and procedures applied:	Estimate calculated from field sampling using the equations given in the methodology
Any comment:	

Data Unit / Parameter:	*sbp*
Data unit:	#
Description:	Small biomass plots
Source of data:	Field survey
Justification of choice of data or description of measurement methods and procedures applied:	Number of plots determined by statistical requirements
Any comment:	

Data Unit / Parameter:	*W*
Data unit:	#
Description:	Number of small biomass plots
Source of data:	Field survey
Justification of choice of data or description of measurement methods and procedures applied:	Number of plots determined by statistical requirements
Any comment:	

Data Unit / Parameter:	b_s
Data unit:	kg
Description:	biomass of the collected small woody and non-woody vegetation in each plot
Source of data:	Field survey
Justification of choice of data or description of measurement methods and procedures applied:	Dry weight of biomass collected from each plot
Any comment:	

Data Unit / Parameter:	A_{sbp}
Data unit:	m2
Description:	Area of the small biomass plot
Source of data:	Field survey
Justification of choice of data or description of measurement methods and procedures applied:	Area of the plot used is determined by the small vegetation density in the stratum
Any comment:	

Data Unit / Parameter:	R_s
Data unit:	Dimensionless
Description:	Root-to-shoot ratio for the small woody and non-woody biomass
Source of data:	Existing data or destructive field sampling
Justification of choice of data or description of measurement methods and procedures applied:	Determination of the root-to-shoot ratio R_s for highly heterogeneous species mixes may be complex. Where different species sampled have different root-to-shoot ratios, the most conservative (smallest) root-to-shoot ratio must be used for the calculations. In many cases, root-to-shoot ratios can be found in the scientific literature. However, consideration should also be given to undertaking excavation and weighing of dry root and top weight for species where good root-to-shoot ratios are not found in the literature, and where the project proponent has reason to believe that the species in question may vary significantly from other species. Since undertaking this measurement may be extremely difficult, the project proponent may alternately propose a root-to-shoot ratio for the species which is demonstrably conservative (for instance, which is lower than the known root-to-shoot ratio for the most comparable species).
Any comment:	

Data Unit / Parameter:	B_i
Data unit:	t
Description:	Total biomass in stratum s
Source of data:	Summed from estimated data
Justification of choice of data or description of measurement methods and procedures applied:	Summed from estimations of total large woody biomass and total small woody and non-woody biomass in the stratum
Any comment:	

7 REFERENCES AND OTHER INFORMATION

CDM AR-AM0001 (now in consolidated methodology CDM AR-ACM0002) AR-ACM0002: http://cdm.unfccc.int/UserManagement/FileStorage/CDM_ACM2B3FZAKHOM5TPX6WC19NDFFPT4J3YE (visited 18-05-2010).

CDM AR-AM0004 Reforestation or afforestation of land currently under agricultural use. ARAM 004 http://cdm.unfccc.int/UserManagement/FileStorage/KYBDLQFMI6R20X58OGH3Z71N9TSU4A (visited 18-05-2010).

IPCC, 2003, GPG-LULUCF (http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_contents.html, last visited 14-09-2011)

CDM A/R Methodological Tool *Calculation of the number of sample plots for measurements within A/R CDM project activities* (AR-AM Tool 03 - Version 02 or later version)

DOCUMENT HISTORY

Version	Date	Comment
v1.0	16 Nov 2012	Initial version released