Approved VCS Module VMD0001
Version 1.0
REDD Methodological Module:
Estimation of carbon stocks in the above- and belowground biomass in live tree and non-tree pools (CP-AB)
Sectoral Scope 14

I. SCOPE, APPLICABILITY AND PARAMETERS

Scope

This module allows for *ex ante* estimation of carbon stocks in above- and belowground tree and non-tree woody biomass in the baseline case (for both pre- and post-deforestation stocks) and project case and for *ex post* estimation of change in carbon stocks in above- and belowground tree biomass in the project case. Uncertainty of estimates is treated in module X-UNC. Identification of baseline (post-deforestation) land-uses and stocks is treated in modules BL-UP and BL-PL.

Applicability

This module is applicable to all forest types and age classes. Inclusion of the aboveground tree biomass pool as part of the project boundary is mandatory as per the framework module REDD-MF.

Non-tree aboveground biomass must be included as part of the project boundary if the following applicability criteria are met (per framework module REDD-MF):

- Stocks of non-tree aboveground biomass are greater in the baseline than in the project scenario, and
- Non-tree aboveground biomass is determined to be significant (using the T-SIG module).

Belowground (tree and non-tree) biomass are not required for inclusion in the project boundary because omission is conservative.

Parameters

This module produces the following parameters:

Parameter	SI Unit	Description
$C_{AB\_tree,\ i}$	t CO_2-e ha^{-1}	Carbon stock in aboveground tree biomass in stratum *i*
$C_{BB\_tree,\ i}$	t CO_2-e ha^{-1}	Carbon stock in belowground tree biomass in stratum *i*
$C_{AB\_non\text{-}tree,\ i}$	t CO_2-e ha^{-1}	Carbon stock in aboveground non-tree biomass in stratum *i*
$C_{BB\_non\text{-}tree,\ i}$	t CO_2-e ha^{-1}	Carbon stock in belowground non-tree biomass in stratum *i*

II. PROCEDURES

Frequency of measurement for baseline above- and belowground biomass stocks

Measurements of initial stocks employed in the baseline must take place within ±5 years of the project start date, for simplicity referred to here as stocks at t=0.

Above- and belowground biomass stock estimates are valid in the baseline (i.e. treated as constant) for 10 years, after which they must be re-estimated from new field measurements. For each stratum, where the re-measured estimate is within the 90% confidence interval of the t=0 estimate, the t=0 stock estimate takes precedence and is re-employed, and where the re-measured estimate is outside (i.e. greater than or less than) the 90% confidence interval of the t=0 estimate, the new stock estimate takes precedence and is used for the subsequent period.

Part 1: Aboveground tree biomass: Estimation of carbon stocks in aboveground tree biomass ($C_{AB\_tree,i}$)

The mean carbon stock in aboveground tree biomass per unit area is estimated based on field measurements in sample fixed area plots or sample points using prisms employing representative random or systematic sampling.

Two methods are available for sampling: Fixed Area Plots and Point Sampling with Prisms, both using Allometric Equations method to estimate biomass from measured tree dimensions.

Part 1, Option 1. Fixed Area Plots with Allometric Equation method

Step 1: Determine the tree dimensions such as diameter (*DBH*, at typically 1.3 m [4.3 ft] aboveground level or above buttress where they exist, and total height H), of all the trees above some minimum *DBH* in the sample plots. The exact tree dimensions and minimum size tree to be measured in sample plots will be specified by the allometric equation selected in Step 2. Any minimum values employed in inventories are held constant for the duration of the project.

Step 2: Select or develop an appropriate and validated allometric equation for forest type/group of species *j* (e.g. tropical humid forest or tropical dry forest) or for each species or family *j* (group of species) found in the inventory (hereafter referred to as species group). Any equation selected may only be used if applicability has been demonstrated and validated per guidance in the parameters section below.

Step 3: Estimate carbon stock in aboveground biomass for each individual tree of species group *j* in the sample plot located in stratum *i* using the selected or developed allometric equation applied to the tree dimensions resulting from Step 1 and sum the carbon stocks in the sample plot:

$$C_{AB\_tree,sp,i} = \sum_{j}^{S} \sum_{l=1}^{N_{j,sp,i}} f_j(X, Y...) * CF_j \quad (1)$$

Where:

$C_{AB\_tree,sp,i}$	Carbon stock in aboveground biomass of trees in plot *sp* in stratum *i*; t C
CF_j	Carbon fraction of biomass for species group *j*; t C t^{-1} d.m.
$f_j(X,Y..)$	Aboveground biomass of trees based on allometric equation for species group *j* based on measured tree variable(s); t. d.m. $tree^{-1}$
i	*1, 2, 3, …M* strata
j	*1, 2, 3 … S* tree species
l	*1, 2, 3, … $N_{j,sp,i}$* sequence number of individual trees of species group *j* in sample plot *sp* in stratum *i*

Step 4: Calculate the mean carbon stock in aboveground biomass for each stratum, converted to carbon dioxide equivalents:

$$C_{AB\_tree,i} = \sum_{sp=1}^{P_i} \frac{C_{AB\_tree,sp,i}}{A_{sp,i}} * \frac{44}{12} \quad (2)$$

Where:

$C_{AB\_tree,i}$	Mean aboveground biomass carbon stock in stratum *i*; t CO_2-e ha^{-1}
$C_{AB\_tree,sp,i,t}$	Aboveground biomass carbon stock of trees in sample plot *sp* of stratum *i* , t C
A_{spi}	Area of sample plot *sp* in stratum *i*; ha
sp	*1, 2, 3 … Pi* sample plots in stratum *i*
i	*1, 2, 3 … M* strata
44/12	Ratio of molecular weight of CO_2 to carbon, t CO_2-e t C^{-1}

Part 1, Option 2: Point Sampling with Allometric Equation method

Step 1: Determine the tree dimensions such as diameter (*DBH*, at typically 1.3 m [4.3 ft] aboveground level and total height H), of all the trees above some minimum *DBH* in the sample plots. The exact tree dimensions and minimum size tree to be measured at sample points will be specified by the allometric equation selected in Step 2. Any minimum values employed in inventories are held constant for the duration of the project.

Step 2: Select or develop an appropriate and validated allometric equation for each species group *j* found in the inventory. Any equation selected may only be used if applicability has been demonstrated and validated per guidance in the parameters section below.

Step 3: Estimate carbon stock in aboveground biomass for each individual tree *l* of species group *j* at the sample point located in stratum *i* using the selected or developed allometric equation applied to the tree dimensions resulting from Step 1, and sum the carbon stocks for the sample point:

$$C_{AB\_tree,j,sp,i,t} = \sum_{j=1}^{S} \sum_{l=1}^{N_{j,sp,i}} \left(\frac{f_j(X,Y...) * CF_j}{(3.1415/10000) * ((DBH/100) * D:RAD)^2} \right) \quad (3)$$

Where:

$C_{AB\_tree,j,sp,i}$	Carbon stock in aboveground biomass of trees of species group *j* at point *sp* in stratum *i*; t C
CF_j	Carbon fraction of biomass for tree species group *j*; t C t^{-1} d.m.
$f_j(X,Y...)$	Allometric equation for species *j* linking measured tree variable(s) to aboveground biomass of trees; t. d.m. $tree^{-1}$
DBH	Diameter at breast height of tree *l* of species group *j* at point *sp* in stratum *i* at time *t*, cm
D:RAD	Ratio of DBH to plot radius, specific to prism Basal Area Factor (BAF) employed in point sampling
l	*1, 2, 3, …* $N_{j,sp,i}$ sequence number of individual trees of species *j* at point *sp* in stratum *i*
i	*1, 2, 3, …M* strata
j	*1, 2, 3 … S* tree species

Step 4: Calculate the mean carbon stock in aboveground biomass for each stratum, converted to carbon dioxide equivalents:

$$C_{AB\_tree,i} = \frac{1}{N} * \sum_{sp=1}^{P_i} C_{AB\_tree,sp,i} * \frac{44}{12} \quad (4)$$

Where:

$C_{AB\_tree,i}$	Mean aboveground biomass carbon stock in stratum *i*; t CO_2-e ha^{-1}
$C_{AB\_tree\_sp,i}$	Mean aboveground biomass carbon stock of trees at point *sp*, in stratum *i*; t C
N	Number of sample points in stratum *i*; dimensionless
sp	*1, 2, 3 … P_i* sample points in stratum *i*
i	*1, 2, 3 … M* strata
44/12	Ratio of molecular weight of CO_2 to carbon, t CO_2-e t C^{-1}

Part 2: Belowground tree biomass: Estimation of carbon stocks in belowground tree biomass ($C_{BB\_tree,i}$)

The mean carbon stock in belowground tree biomass per unit area is estimated based on field measurements in sample fixed area plots or sample points using prisms, employing representative random or systematic sampling. The mean carbon stock in belowground tree biomass per unit area is estimated based on field measurements of aboveground parameters in sample plots. Root to shoot ratios are coupled with the Allometric Equations method Part 1 Options 1 and 2, to calculate belowground from aboveground biomass.

Part 2, Option 1: Fixed area plots with root to shoot ratio

Step 1: Calculate the belowground tree biomass carbon stock for each plot:

The above ground tree biomass carbon stocks in each plot can be estimated by allometric equation method described in Part 1 Option 1.

$$C_{BB\_tree,sp,i} = R * C_{AB\_tree,sp,i} \quad (5)$$

Where:

$C_{BB\_tree,sp,i}$	Belowground tree biomass carbon stock of trees in plot *sp*, in stratum *i*; t C
$C_{AB\_tree,sp,i}$	Aboveground tree biomass carbon stock of trees in plot *sp*, in stratum *i*; t C
R	Root to shoot ratio; t root d.m. t^{-1} shoot d.m.
i	*1, 2, 3, …M* strata

Step 2: Calculate the mean belowground tree biomass carbon stock for each stratum, converted to carbon dioxide equivalents:

$$C_{BB\_tree,i} = \sum_{sp=1}^{P_i} \frac{C_{BB\_tree\_sp,i}}{A_{sp,i}} * \frac{44}{12} \quad (6)$$

Where:

$C_{BB\_tree,i}$	Mean belowground tree biomass carbon stock in stratum *i*; t CO_2-e ha^{-1}
$C_{BB\_tree\_sp,i}$	Mean belowground tree biomass carbon stock of trees in plot *sp*, in stratum *i*; t C
Asp_i	Area of sample plot *sp* in stratum *i*; ha
sp	*1, 2, 3 … P_i* sample plots in stratum *i*
i	*1, 2, 3 … M* strata
44/12	Ratio of molecular weight of CO_2 to carbon, t CO_2-e t C^{-1}

Part 2, Option 2. Point Sampling with root to shoot ratio

Step 1: Calculate the belowground tree biomass carbon stock for each point sampled:

The above ground tree biomass carbon stocks in each point sampled can be found using the allometric equation method described in Part 1 Option 2 above.

$$C_{BB\_tree,sp,i} = R * C_{AB\_tree,sp,i} \quad (7)$$

Where:

$C_{BB\_tree,sp,i}$	Belowground tree biomass carbon stock of trees in point *sp*, in stratum *i*; t C
$C_{AB\_tree,sp,i}$	Aboveground tree biomass carbon stock of trees in point *sp*, in stratum *i*; t C
R	Root to shoot ratio; t root d.m. t^{-1} shoot d.m.
i	*1, 2, 3, …M* strata

Step 2: Calculate the mean belowground tree biomass carbon stock for each stratum, converted to carbon dioxide equivalents:

$$C_{BB\_tree,i} = \frac{1}{N} * \sum_{sp=1}^{P_i} C_{BB\_tree\_sp,i} * \frac{44}{12} \quad (8)$$

Where:

$C_{BB\_tree,i}$	Mean belowground tree biomass carbon stock in stratum *i*; t CO_2-e ha^{-1}
$C_{BB\_tree\_sp,i}$	Mean belowground tree biomass carbon stock of trees at point *sp*, in stratum *i*; t C
N	Number of sample points in stratum *i*; dimensionless
sp	*1, 2, 3 … P_i* sample points in stratum *i*

i	*1, 2, 3 … M* strata
44/12	Ratio of molecular weight of CO_2 to carbon, t CO_2-e t C^{-1}

Part 3: Aboveground non-tree biomass: Estimation of carbon stocks in aboveground non-tree woody biomass ($C_{AB\_nontree,i}$)

The mean carbon stocks in the non-tree aboveground biomass pool per unit area are estimated based on previously published or default data[1] or field measurements. Non-tree woody aboveground biomass pool includes trees smaller than the minimum tree size measured in the tree biomass pool, all shrubs, and all other non-herbaceous live vegetation[2].

Non-tree vegetation can be sampled using destructive sampling frames and/or, where suitable, in sampling plots in combination with an appropriate allometric equation for shrubs.

Calculate the mean carbon stock in aboveground non-tree biomass for each stratum by adding the mean carbon stock in aboveground biomass calculated using the sampling frame method to the mean carbon stock in aboveground biomass calculated using the allometric equation method.

$$C_{AB\_nontree,i} = C_{AB\_nontree-sample,i} + C_{AB\_nontree\_allometric,i} \qquad (9)$$

Where:

$C_{AB\_nontree,i}$	Mean aboveground non-tree biomass carbon stock in stratum *i*; t CO_2-e ha^{-1}
$C_{AB\_nontree\_sample,i}$	Mean aboveground non-tree biomass carbon stock in stratum *i* from sample frame method; t CO_2-e ha^{-1}
$C_{AB\_nontree\_allometric,i}$	Mean aboveground non-tree biomass carbon stock in stratum *i* from allometric equation method; t CO_2-e ha^{-1}
i	*1, 2, 3 … M* strata

Part 3, Option 1. Sampling Frame Method:

In a stratum where non-tree vegetation is spatially variable, large frames should be used (e.g. 1-2 m radius circle). Where non-tree vegetation is homogeneous, smaller frames can be used (e.g. 30 cm radius).

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1 Where using published or default data these data must be derived from peer-reviewed literature and must be appropriate to the species in the project area or to the geographic region, elevation and precipitation regime in the project area

2 Pursuant to AR-WG 21 that the GHG emissions from removal of herbaceous vegetation are insignificant in A/R CDM project activities and therefore these emissions can be neglected in A/R baseline and monitoring methodologies

Generally, the frame is placed at a randomly or systematically selected GPS point or tree plot. At each location, all vegetation originating from inside the frame is cut at the base and weighed. One representative subsample of the cut material is weighed to obtain its wet mass. The collected subsample is taken to a laboratory, oven dried and weighed to determine the dry mass. The wet to dry ratio of the subsample is then used to estimate the dry mass of the original sample.

To estimate the mean carbon stock per unit area in the aboveground non-tree biomass for each stratum:

$$C_{AB\_nontree\_sample,i} = \sum_{sfp=1}^{SFP_i} \frac{C_{AB\_nontree\_sample,sf,i}}{A_{sfp,i}} * CF * \frac{44}{12} \tag{10}$$

Where:

$C_{AB\_nontree\_sample,i}$	Carbon stock in aboveground non-tree vegetation in sampling plot in strata *i* from sample method; t CO_2-e ha^{-1}
$C_{AB\_,nontree\_sample,sp,i}$	Carbon stock in aboveground non-tree vegetation in sample plot *sfp* in stratum *i* from sampling frame method; kg d.m.
CF_j	Carbon fraction of dominant non-tree vegetation *j*; t C t $d.m.^{-1}$
A_{sfpi}	Area of non-tree sampling plot *s fp* in stratum i; ha
sfp	*1, 2, 3 … SFP_i* sample plots in stratum *i*
i	*1, 2, 3 … M* strata
44/12	Ratio of molecular weight of CO_2 to carbon, t CO_2-e t C^{-1}

Part 3, Option 2. Allometric Equation Method:

This method may be used for shrubs, bamboo, or other vegetation types where individuals can be clearly delineated.

Step 1: Select or develop an appropriate allometric equation (if possible species-specific, or if not from a similar species).

Step 2: Estimate carbon stock in aboveground biomass for each individual *l* in the sample plot *r* located in stratum *i* using the selected or developed allometric equation:

$$C_{AB\_nontreeallometric,i,r} = \sum_{j=1}^{S}\sum_{l=1}^{N_{i,r}} f_j(vegatationparameters) * CF_j \tag{11}$$

Where:

$C_{AB\_nontree\_allometric,i,r}$	Carbon stock in aboveground biomass of non-tree sample plot *r* in stratum *i* from allometric equation method; t C

CF_j	Carbon fraction of biomass for species *j*; t C t^{-1} d.m.
f_j*(vegetation parameters)*	Aboveground biomass from allometric equation for species *j* linking parameters such as stem count, diameter of crown, height, or others ; t. d.m. $individual^{-1}$
i	*1, 2, 3, …M* strata
r	*1, 2, 3, …R* non-tree allometric method sample plots in stratum *i*
j	*1, 2, 3 … S* species
l	*1, 2, 3, …* $N_{i,r}$ sequence number of individuals in sample plot *r* in stratum *i*
t	*0, 1, 2, 3 …t** years elapsed since start of the REDD project activity

Step 3: Calculate the mean carbon stock in aboveground biomass for each stratum, converted to carbon dioxide equivalents:

$$C_{AB\_nontree\_allometric,i} = \sum_{r=1}^{R_i} \frac{C_{AB\_nontree\_allometric,r,i}}{Ar_i} * \frac{44}{12} \quad (12)$$

Where:

$C_{AB\_nontree\_allometric,i}$	Mean aboveground biomass carbon stock in stratum *i* from allometric equation method; t CO_2-e ha^{-1}
$C_{AB\_nontree\_allometricr,I,t}$	Aboveground biomass carbon stock in non-tree vegetation in sample plot *r* of stratum *i* from non-tree allometric sample plots, t C
Ar_i	Area of non-tree allometric method sample plot in stratum *i*; ha
r	*1, 2, 3 …R* non-tree allometric method sample plots in stratum *i*
i	*1, 2, 3 … M* strata
44/12	Ratio of molecular weight of CO_2 to carbon, t CO_2-e t C^{-1}

Part 4: Belowground non-tree biomass: Estimation of belowground carbon stocks in non-tree vegetation ($C_{BBnontree,i}$)

The mean carbon stock in belowground biomass per unit area is estimated based on field measurements of aboveground parameters in sample plots. Root to shoot ratios are coupled with the aboveground biomass estimate to calculate belowground from aboveground biomass.

Step 1: Select an appropriate root to shoot ratio for non-tree biomass.

Step 2: Use the appropriate root to shoot ratio to estimate the belowground biomass from aboveground biomass carbon stock in non-tree vegetation in sample plot *sp* of stratum *i*, t C:

$$C_{BB_{nontree},i,sp} = C_{AB_{nontree},i,sp} * R \quad (13)$$

Where:

$C_{AB\_nontree,i,sp}$	Aboveground biomass carbon stock in non-tree vegetation in sample plot *sp* of stratum *i*, t C
$C_{BB\_nontree,i,sp,t}$	Belowground biomass carbon stock in non-tree vegetation in sample plot *sp* of stratum *i*, t C
R	Root to shoot ratio; t root d.m. t^{-1} shoot d.m.
I	*1, 2, 3 … M* strata
sp	*1, 2, 3 … P_i* sample plots in stratum *i*

Step 3: Calculate the mean carbon stock in belowground biomass for each stratum, converted to carbon dioxide equivalents:

$$C_{BB\_nontree,i} = \sum_{sp=1}^{P_i} \frac{C_{BB\_nontree,sp,i}}{A_{sp,i}} * \frac{44}{12} \quad (14)$$

Where:

$C_{BB\_nontree,i}$	Mean belowground biomass carbon stock in stratum *i*; t CO_2-e ha^{-1}
$C_{BB\_nontree,i,sp}$	Belowground biomass carbon stock in non-tree vegetation in sample plot *sp* of stratum *i*; t C
A_{spi}	Area of sample plot *sp* in stratum *i*; ha
sp	*1, 2, 3 … Pi* sample plots in stratum *i*
i	*1, 2, 3 … M* strata
44/12	Ratio of molecular weight of CO_2 to carbon, t CO_2-e t C^{-1}

III. DATA AND PARAMETERS NOT MONITORED (DEFAULT OR POSSIBLY MEASURED ONE TIME)

Data / parameter:	*CF*
Data unit:	t C t d.m.$^{-1}$
Used in equations:	1,3,10,11
Description:	Carbon fraction of dry matter in t C t^{-1} d.m.
Source of data:	Values from the literature (e.g. IPCC 2006 INV GLs AFOLU Chapter 4 Table 4.3) shall be used if available, otherwise default value of 0.47 t C t^{-1} d.m. can be used

Measurement procedures (if any):	
Any comment:	Where new species are encountered in the course of monitoring, new carbon fraction values must be sourced from the literature or otherwise use the default value.

Data / parameter:	*D:RAD*
Data unit:	Dimensionless
Used in equations:	3
Description:	Ratio of DBH to plot radius, specific to prism Basal Area Factor (BAF) employed in point sampling
Source of data:	see table below
Measurement procedures (if any):	None
Any comment:	

BAF (m^2/ha)	D:RAD
2	35.4
3	28.9
4	25.0
5	22.4
6	20.4
7	18.9
8	17.7
9	16.7

Data / parameter:	$f_j(X,Y)$
Data unit:	t d.m. tree^{-1}
Used in equations:	1,3
Description:	Allometric equation for species *j* linking measured tree variable(s) to aboveground biomass of living trees, expressed as t d.m. tree^{-1}
Source of data:	Equations must have been derived using a wide range of measured variables (e.g. DBH, Height, etc.) based on datasets that comprise at least

	30 trees. Equations must be based on statistically significant regressions and must have an r^2 that is ≥ 0.8. The source of equation(s) shall be chosen with priority from higher to lower preference, as available, as follows: (a) National species-, genus-, family-specific; (b) Species-, genus-, family-specific from neighboring countries with similar conditions (i.e. broad continental regions); (c) National forest-type specific; (d) Forest-type specific from neighboring countries with similar conditions (i.e. broad continental regions); (e) Pan-tropical forest type-specific such as those provided Tables 4.A.1 to 4.A.3 of the GPG-LULUCF (IPCC 2003) or in Pearson, T., Walker, S. and Brown, S. 2005. Sourcebook for Land Use, Land-Use Change and Forestry Projects. Winrock International and the World Bank Biocarbon Fund. 57pp. Available at: http://www.winrock.org/Ecosystems/files/Winrock-BioCarbon_Fund_Sourcebook-compressed.pdf or in Chave, J., C. Andalo, S. Brown, M. A. Cairns, J. Q. Chambers, D. Eamus, H. Folster, F. Fromard, N. Higuchi, T. Kira, J.-P. Lescure, B. W. Nelson, H. Ogawa, H. Puig, B. Riera, T. Yamakura. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia 145: 87-99. Species-, genus- and family-specific allometric equations may not always be available, and may be difficult to apply with certainty in the typically species rich forests of the humid tropics, hence it is acceptable practice to use equations developed for regional or pantropical forest types, provided that their accuracy has been validated with direct site-specific data (per guidance below). If a forest-type specific equation is used, it should not be used in combination with species-specific equation(s) (i.e. it must be used for all tree species[3]).
Measurement procedures (if any):	
Any comment:	It is necessary to validate the applicability of equations used. Source data from which equation was derived should be reviewed and confirmed to

[3] Note that forest type specific and pantropical equations will typically not include palm species or hollow-stem species (e.g. Cecropia) and so specific equations for these growth forms will be needed

	be representative of the forest type/species and conditions in the project and covering the range of potential independent variable values.
	
	Allometric equations can be validated either by:
	
	1. Limited Measurements
	
	• Select at least 30 trees (if validating forest type-specific equation, selection should be representative of the species composition in the project area, i.e. species representation in roughly in proportion to relative basal area). Minimum diameter of measured trees shall be 20cm and maximum diameter shall reflect the largest trees present or potentially present in the future in the project area (and/or leakage belt)
	• Measure DBH, and height to a 10 cm diameter top or to the first branch.
	• Calculate stem volume from measurements and multiplying by species-specific density to gain biomass of bole.
	• Apply a biomass expansion factor to estimate total aboveground biomass from stem biomass. For broadleaf tropical trees this factor shall be:
	    o 1.38 for trees 20-40cm
	    o 1.33 for trees 40-80cm
	    o 1.25 for trees ≥ 80cm[4]
	• Plot all the estimated biomass of all the measured trees along with the curve of biomass against diameter as predicted by the allometric equation. If the estimated biomass of the measured trees are distributed both above and below the curve (as predicted by the allometric equation) the equation may be used. The equation may also be used if the measured individuals have a biomass consistently higher than predicted by the equation. If plotting the biomass of the measured trees indicates a systematic bias to overestimation of biomass (>75% of the trees above the predicted curve) then destructive sampling must be undertaken, or another equation selected.
	
	or
	
	2. Destructive Sampling
	
	• Select at least five trees (if validating forest type-specific equation, selection should be representative of the species composition in the project area, i.e. species representation in roughly in proportion to relative basal area) at the upper end of the range of independent

4 Biomass expansion factors conservatively selected from destructively sampled trees in Bolivia and Belize, reference to IPCC GPG LULUCF BEF values and expert opinion.

	variable values existing in the project area • Measure DBH and commercial height and calculate volume using the same procedures/equations used to generate commercial volumes to which BCEFs will be applied • Fell and weigh the aboveground biomass to determine the total (wet) mass of the stem, branch, twig, leaves, etc. Extract and immediately weigh subsamples from each of the wet stem and branch components, followed by oven drying at 70 degrees C to determine dry biomass; • Determine the total dry weight of each tree from the wet weights and the averaged ratios of wet and dry weights of the stem and branch components. • Plot the biomass of all the harvested trees along with the curve of biomass against diameter as predicted by the allometric equation. If the biomass of the harvested trees are distributed both above and below the curve (as predicted by the allometric equation) the equation may be used. The equation may also be used if the harvested individuals have a biomass consistently higher than predicted by the equation. If plotting the biomass of the harvested trees indicates a systematic bias to overestimation of biomass (>75% of the trees below the predicted curve) then additional destructive sampling must be undertaken, or another equation selected. Details of destructive sampling measurements are given in: Brown, S. 1997. Estimating biomass and biomass change of tropical forests: a primer. FAO Forestry Paper 134, Rome, Italy. Available at http://www.fao.org/docrep/W4095E/W4095E00.htm If using species-specific equations, and new species are encountered in the course of monitoring, new allometric equations must be sourced from the literature and validated, if necessary, as per requirements and procedures above.

Data / parameter:	f_j*(vegetation parameters)*
Data unit:	t. d.m. individual^{-1}
Used in equations:	11
Description:	Allometric equation for non-tree species / linking parameters such as stem count, diameter of crown, height, or others to aboveground biomass of an individual
Source of data:	Whenever available, use allometric equations that are species-specific or group of species-specific, provided the equations have been derived

	using a wide range of diameters and heights, based on datasets that comprise at least 30 individuals. Project participants may create project location specific equation where appropriate.
Measurement procedures (if any):	It is necessary to verify the applicability of existing equations used. Allometric equations can be verified either by: 1. Review of source data from which equation was derived and confirmation that the source data is representative of the species and conditions in the project and covers the range of potential sizes. Or 2. Destructive Sampling • Selecting at least five individuals covering the range of sizes existing, and felling and weighing the aboveground biomass to determine the total (wet) mass of the stem and branch components; • Extracting and immediately weighing subsamples from each of the wet stem and branch components, followed by oven drying at 70°C to determine dry biomass; • Determining the total dry weight of each individual from the wet weights and the averaged ratios of wet and dry weights of the stem and branch components. If the biomass of the harvested individual is within ±10% of the mean values predicted by the selected allometric equation, and is not biased, then mean values from the equation may be used. Otherwise, the equation must be re-parameterized to conform to the validation data before using, or another equation selected. To create a new allometric equation: Follow guidance in: Pearson, T., Walker, S. and Brown, S. 2005. Sourcebook for Land Use, Land-Use Change and Forestry Projects. Winrock International and the World Bank Biocarbon Fund. 57pp. Available at: http://www.winrock.org/Ecosystems/files/Winrock-BioCarbon_Fund_Sourcebook-compressed.pdf
Any comment:	

Data / parameter:	*R*
Data unit:	t root d.m. t^{-1} shoot d.m.

Used in equations:	5,7,13
Description:	Root to shoot ratio appropriate to species or forest type / biome; note that as defined here, root to shoot ratio is applied as belowground biomass per unit area:aboveground biomass per unit area (not on a per stem basis)
Source of data:	The source of data shall be chosen with priority from higher to lower preference as follows: (a) Detailed data collected using common practices for root sampling in the area; (b) Globally forest type-specific or eco-region-specific (e.g. IPCC GPG-LULUCF). *Root to shoot ratios for tropical and subtropical forests modified from Table 4.4. in IPCC GL AFOLU*

Domain	Ecological Zone	Aboveground biomass	Root-to-shoot ratio	Range
Tropical	Tropical rainforest	*<125 $t.ha^{-1}$*	0.20	*0.09-0.25*
		>125 $t.ha^{-1}$	0.24	*0.22-0.33*
	Tropical dry forest	*<20 $t.ha^{-1}$*	0.56	*0.28-0.68*
		>20 $t.ha^{-1}$	0.28	*0.27-0.28*
Subtropical	Subtropical humid forest	*<125 $t.ha^{-1}$*	0.20	*0.09-0.25*
		>125 $t.ha^{-1}$	0.24	*0.22-0.33*
	Subtropical dry forest	*<20 $t.ha^{-1}$*	0.56	*0.28-0.68*
		>20 $t.ha^{-1}$	0.28	*0.27-0.28*

Measurement procedures (if any):	
Any comment:	Guidelines for Conservative Choice of Default Values: 1. If in the sources of data mentioned above, default data are available for conditions that are similar to the project (similar forest or vegetation type; same climate zone), then mean values of default data may be used and considered conservative. 2. Global values may be selected from Table 4.4 (modified as given above) of the AFOLU Guidelines (IPCC 2006), by choosing a climatic zone and forest type that most closely matches the project circumstances.

IV. DATA AND PARAMETERS MONITORED

Data / parameter:	A_{sp}
Data unit:	ha
Used in equations:	2,6,14
Description:	Area of sample plots in ha
Source of data:	Recording and archiving of number and size of sample plots
Measurement procedures (if any):	
Monitoring frequency:	Monitoring must occur at least every ten years for baseline renewal. Where carbon stock enhancement is included monitoring shall occur at least every five years
QA/QC procedures:	
Any comment:	Where carbon stock estimation occurs only for determination of the baseline this parameter shall be known *ex-ante*. Where part of project monitoring, *ex-ante* the number and area of sample plots shall be estimated based on projected sample effort relative to projections of growth and emissions.

Data / parameter:	N
Data unit:	Dimensionless
Used in equations:	4,8
Description:	Number of sample points
Source of data:	Recording and archiving of number of sample points
Measurement procedures (if any):	
Monitoring frequency:	Monitoring must occur at least every ten years for baseline renewal. Where carbon stock enhancement is included monitoring shall occur at least every five years
QA/QC procedures:	
Any comment:	Where carbon stock estimation occurs only for determination of the baseline this parameter shall be known *ex-ante*. Where part of project monitoring, *ex-ante* the number of sample plots shall be estimated based

	on projected sample effort relative to projections of growth and emissions.

Data / parameter:	*DBH*
Data unit:	cm
Used in equations:	1,3
Description:	Diameter at breast height of a tree in cm
Source of data:	Field measurements in sample plots
Measurement procedures (if any):	Typically measured 1.3m aboveground. Measure all trees above some minimum *DBH* in the sample plots. The minimum *DBH* varies depending on tree species and climate; for instance, the minimum *DBH* may be as small as 2.5 cm or as high as 20 cm, but for himud tropical forests 10 cm is commonly used. Minimum DBH employed in inventories is held constant for the duration of the project.
Monitoring frequency:	Monitoring must occur at least every ten years for baseline renewal. Where carbon stock enhancement is included monitoring shall occur at least every five years
QA/QC procedures:	Standard quality control / quality assurance (QA/QC) procedures for forest inventory including field data collection and data management shall be applied. Use or adaptation of QA/QCs already applied in national forest monitoring, or available from published handbooks, or form the *IPCC GPG LULUCF 2003*, is recommended.
Any comment:	Where carbon stock estimation occurs only for determination of the baseline this parameter shall be known *ex-ante*. Where part of project monitoring, *ex-ante* DBH shall be estimated based on projections of growth.

Data / parameter:	A_{sf}
Data unit:	m^{-2}
Used in equations:	10
Description:	Area of one sampling frame
Source of data:	Recording and archiving size of sampling frame plot
Measurement procedures (if any):	
Monitoring	Monitoring must occur at least every ten years for baseline renewal.

frequency:	Where carbon stock enhancement is included monitoring shall occur at least every five years
QA/QC procedures:	
Any comment:	Shall be known *ex-ante*.

Data / parameter:	*Ar*
Data unit:	Hectares
Used in equations:	12
Description:	Total area of all non-tree allometric method sample plots in stratum *i*
Source of data:	Recording and archiving size of non-tree allometric method sample plot
Measurement procedures (if any):	
Monitoring frequency:	Monitoring must occur at least every ten years for baseline renewal. Where carbon stock enhancement is included monitoring shall occur at least every five years
QA/QC procedures:	
Any comment:	Where carbon stock estimation occurs only for determination of the baseline this parameter shall be known *ex-ante*. Where part of project monitoring, *ex-ante* the number and area of sample plots shall be estimated based on projected sample effort relative to projections of growth and emissions.

Data / parameter:	*H*
Data unit:	m
Used in equations:	1,3
Description:	Total height of tree
Source of data:	Field measurements in sample plots
Measurement procedures (if any):	
Monitoring frequency:	Monitoring must occur at least every ten years for baseline renewal. Where carbon stock enhancement is included monitoring shall occur at least every five years

QA/QC procedures:	
Any comment:	Where carbon stock estimation occurs only for determination of the baseline this parameter shall be known *ex-ante*. Where part of project monitoring, *ex-ante* height shall be estimated based on projections of growth.