WR Methodological Module
Estimation of Carbon Stocks in Tree Biomass (CP-TB)

I. SCOPE, APPLICABILITY AND PARAMETERS

Scope

This module allows for *ex-ante* estimation of carbon stocks of above- and belowground tree woody biomass for the baseline and project cases, and for *ex-post* estimation of change of carbon stocks of tree biomass for the baseline and project cases. Uncertainty of estimates is treated in module X-UNC. Identification of baseline land-uses is treated in modules BL-WR, BL-WR-WL, BL-WR-HM, and BL-WR-HM-WL.

Applicability

This module is applicable to wetland forests located in the in the Mississippi Delta. This module is applicable if the tree biomass carbon pool is included as part of the project boundary as per the determination of the GHG assessment boundary in the framework module WR-MF.

Non-tree aboveground biomass, wetland floor litter and dead wood are not required for inclusion in the project boundary because omission is conservative and some percentage will be quantified in the soil organic carbon (SOC) pool since they become part of the SOC pool over time.

Parameters

This methodology produces the following parameters:

Parameter	SI Unit	Description
ΔC_{TREE}	t CO_2-e	Cumulative total tree carbon stock changes
ΔC_{TREE_BSL}	t CO_2-e	Cumulative total tree carbon stock changes for the baseline scenario

II. PROCEDURES

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.

The mean carbon stock in aboveground tree biomass per unit area is estimated based on field measurements of all trees or of those in fixed area plots using allometric equations. The number and size of plots should ensure adequate representation of the area being measured by utilizing module T-PLOTS.

The allometric method directly calculates aboveground tree biomass by using equations that express aboveground tree biomass as a function of diameter at breast height (DBH) and/or tree height (H; Table 1). Total tree biomass is then obtained by multiplying the aboveground tree biomass by (1+*R*) where *R* is the root-shoot ratio.

Carbon stock can be calculated by multiplying aboveground biomass by the carbon fraction of tree biomass (e.g., ≈ 0.47)[1]. Annual increases in carbon stock are equivalent to carbon sequestered.

Table 1. Examples of species-specific regression equations that can be used to calculate whole tree biomass estimates on the basis of tree diameter measurements[2,3,4].

Species	Units		Conversions	Range	Source
Taxodium distichum	kg	=	10^(-.97+2.34*LOG10(DBHcm))	>10 cm	Megonigal et al. '97
Nyssa aquatica	kg	=	10^(-.919+2.291*LOG10(DBHcm))	>10 cm	Megonigal et al. '97
Acer rubrum	kg	=	((2.39959*((DBHcm*0.394)^2)^1.2003))*0.454	10-28 cm	Megonigal et al. '97
Quercus nigra	kg	=	((3.15067*((DBHcm*0.394)^2)^1.21955))*0.45	10-28 cm	Megonigal et al. '97
Salix spp.	kg	=	10^(–2.2094+ 2.3867* ln DBHcm)	>2.5 cm	Jenkins et al. 2003
Avicennia germinans	kg	=	1.934-0.395*DBHcm	0.7-21.5 cm	Smith and Whelan 2006
Laguncularia racemosa	kg	=	1.920-0.441*DBHcm	0.5-18 cm	Smith and Whelan 2006
Rhizophora mangle	kg	=	1.731-0.112*DBHcm	0.5-20 cm	Smith and Whelan 2006

1 Lamlom, S.H., and R.A. Savidge. 2003. A reassessment of carbon content in wood: variation within and between 41 North American species. Biomass and Bioenergy 25: 381–388.

2 Megonigal, J. P., W. H. Conner, S. Kroeger and R. R. Sharitz, 1997. Aboveground Production in Southeastern Floodplain Forests: A Test of the Subsidy-Stress Hypothesis. Ecology 78: 370-384.

3 Jenkins, J.C., D.C. Chojnacky, L.S. Heath, and R.A. Birdsey. 2003. National-Scale Biomass Estimators for United States Tree Species. *Forest Science 49(1): 12-35.*

4 Smith, T.J., and K.R.T. Whelan. 2006. Development of allometric relations for three mangrove species in South Florida for use in the Greater Everglades Ecosystem restoration. Wetlands Ecology and Management 14:409–419.

1.0 Carbon Stock of Living Trees

Carbon stock in living trees (C_{TREE}) is calculated using allometric equations that express aboveground tree biomass as a function of diameter at breast height (*DBH*) and/or tree height (*H*), and which are readily available for forested wetlands. See Table 1 for equations for many typical wetland species. These equations provide for the calculations to be performed for each stratum. If there is more than one stratum, the outcome will be summed over all the strata to obtain the value for the whole project.

1.1. Ex-ante baseline and project

Estimation based on existing biomass density data

If published data are available from which biomass density per unit area for the project area can be estimated, the data may be used if the estimated value of biomass density per unit area does not underestimate biomass in the project area. In this case, the biomass of living trees at the start of the project activity (C_{TREE}) is calculated as:

(1)

$$C_{TREE} = \frac{44}{12} \left(BD_{TREE} * A_{TREE} * CF_{TREE} * (1+R_j) \right)$$

where:

C_{TREE}	Carbon stock of living trees at the start of the project activity; t CO_2-e
44/12	Ratio of molecular weight of CO_2 to carbon; dimensionless
BD_{TREE}	Tree biomass density per unit area of the project area (obtained from published literature); metric ton d.m. ha^{-1}
A_{TREE}	Area of land within the project boundary where living trees are standing at the start of the project activity; ha
CF_{TREE}	Carbon fraction of dry matter for tree biomass; ton C ton^{-1} d.m.
R_j	Root-shoot ratio for tree species or group of species *j;* dimensionless

Estimation based on existing DBH data

(i) For each tree species or group of species, select an allometric equation from existing data or literature.

(ii) Obtain the diameter at breast height (*DBH*) and/or tree height (*H*) corresponding to the age of trees at a given time;

(iii) Insert the diameter at breast height (*DBH*) and/or tree height (*H*) into the allometric equations and calculate the total aboveground tree biomass per unit area according to the project planting/management plan using the equations below.

1.2 Ex-post baseline and project

Cumulative tree carbon stock changes (ΔC_{TREE})

The carbon stock generated over a given period of time in the project area is calculated based on field measurements at permanent sample plots during a point of time in year t_1 and again during a point of time in year t_2. The cumulative carbon stocks (ΔC_{TREE}) generated from t_1 to t_2 should be calculated using the following equation:

(2)

$$\Delta C_{TREE} = C_{TREEt_2} - C_{TREEt_1}$$

where:

ΔC_{TREE}	Cumulative tree carbon stock changes from time t_1 *to* t_2; t CO_2-e
C_{TREEt2}	Carbon stock of living trees in the project area at time t_2; t CO_2-e
C_{TREEt1}	Carbon stock of living trees in the project area at time t_1; t CO_2-e

Note: At start of the project activity (that is for t_1=0) the baseline tree biomass is equal to initial biomass under the project, that is, the value of C_{TREEt1} in equation 2 is set equal to the baseline C stock as calculated in the baseline module (e.g. BL-WR). When used to calculate ex-post baseline tree carbon stocks for a given period of time, ΔC_{TREE} should be denoted as ΔC_{TREE_BSL}.

The ex-post carbon stock of living trees in the baseline at the start of the project activity should be estimated using one of the two following methods:

Estimation of C_{TREE} based on complete inventory of trees

If the trees are few and scattered, all the trees must be inventoried and dimensional measurements (diameter or height or both) must be collected. Biomass of living trees are calculated as:

(3)

$$C_{TREE} = \sum_{k=1}^{n} \frac{44}{12} \left(F_{j(k)}(DBH,H) * CF_j * (1+R_j) \right)$$

where:

C_{TREE}	Carbon stock of living trees in the project area; t CO_2-e
44/12	Ratio of molecular weight of CO_2 to carbon; dimensionless
$F_{j(k)}(DBH,H)$	Allometric equation for species *j* of the k^{th} tree linking diameter at breast height (*DBH*) and possibly tree height (*H*) to aboveground biomass of living trees; ton d.m.
CF_j	Carbon fraction of biomass for the j^{th} tree species; ton C ton^{-1} d.m.
R_j	Root-shoot ratio for tree species or group of species *j;* dimensionless
j	*1, 2, 3, …* tree species or group of species in the project scenario
k	*1,2,3, … n* individual trees in the baseline at start of the project activity

When equation 3 is applied at two consecutive years t_1 and t_2 (e.g., two consecutive verification years) it provides two values C_{TREEt1} and C_{TREEt2} that are then inserted in equation 2.

Estimation of C_{TREE} based on an inventory of trees in sample plots
If the number of trees in the baseline scenario is too large for a complete inventory to be taken, then sample plots should be delineated and dimensional measurements carried out on the trees in these sample plots. The following step-by-step procedure shows how this method is practically applied:

Step 1. *Ex-post* estimation of tree biomass must be based on actual measurements carried out on trees in permanent sample plots. The permanent sample plots are laid out according to the approved methodological tool T-PLOTS.

The following sub-steps apply for *ex-post* estimation.

(i) Select an allometric equation for the tree species or group of species;
(ii) Depending on the allometric equation, measure the diameter at breast height (*DBH*) and/or tree height (*H*) of all trees in the permanent sample plots;
(iii) Apply the DBH data to the allometric equations and calculate the total aboveground tree biomass for each sample plot.

Step 2. Convert the aboveground tree biomass to total carbon stock in tree biomass using the following equation:

(4)

$$C_{TREE,p} = \sum_{j=1}^{n} \frac{44}{12} (F_j(DBH,H) * CF_j * (1+R_j))$$

where:

$C_{TREE,p}$	Carbon stock in living trees in sampling plot *p*; t CO_2-e
44/12	Ratio of molecular weight of CO_2 to carbon; dimensionless
$F_j(DBH,H)$	Allometric equation for species *j* linking diameter at breast height (*DBH*) and possibly tree height (*H*) to aboveground biomass of living trees; ton d.m.
CF_j	Carbon fraction of biomass for tree species or group of species *j*; ton C ton^{-1} d.m.
R_j	Root-shoot ratio for tree species or group of species *j;* dimensionless
j	*1, 2, 3, … n* tree species or group of species in the project scenario

Step 3. The total carbon stock in tree biomass is calculated as follows:

(5)

$$C_{TREE} = \frac{A_t}{A_p} (\sum_{p=1}^{n} C_{TREE,p})$$

where:

C_{TREE}	Carbon stock of living trees in the project area; t CO_2-e
A_t	Total project area; ha
A_p	Total area of sample plots; ha

$C_{TREE,p}$ Carbon stock in living trees in sampling plot *p* at the start of the project activity; t CO_2-e

p *1, 2, 3, … n* sample plots

When equation 5 is applied at two consecutive years t_1 and t_2 (e.g., two consecutive verification years) it provides two values C_{TREEt1} and C_{TREEt2} that are then inserted in equation 2.

EX-ANTE ESTIMATION METHODS

The Project Proponent must make an *ex-ante* calculation of all net anthropogenic GHG removals and emissions for all included sinks and sources for the entire crediting period. Project Proponent shall provide estimates of the values of those parameters that are not available before the start of monitoring activities. Project Proponent must retain a conservative approach in making these estimates.

Ex-ante net GHG removals by sinks can be estimated using empirical methods or modeling based on peer-reviewed literature or field monitoring, reference sample plots or field monitoring of similar sites, and approved local or national parameters that conform to the applicability conditions of this methodology in order to assess the verifiable changes in carbon pools. The methodology ensures that the net anthropogenic GHG removals by sinks are estimated under the project in a conservative manner taking into account the uncertainties associated with the secondary data.

This methodology provides for the use of empirical methods as stand alone or as complements to modeling based on peer reviewed literature for the purpose of *ex-ante* estimation of carbon stock changes. The empirical methods are the methods used in forest/wetland inventory and wetland management studies for estimating biomass, productivity etc. The data from research and published literature that use scientifically accepted empirical methods can be used for *ex-ante* estimation purposes provided such data are based on valid sampling and statistical procedures and are in agreement with the methods, steps and procedures outlined for the estimation of carbon pools under this methodology. For example, species data based on yield tables, peer-reviewed literature, national inventory data or default data, allometric equations, growth models, mortality studies, biomass estimation and nutrient cycling studies and local research such as land records, field surveys, archives, maps or satellite images of the land use/cover before the start of the proposed project activity, field surveys, and expert opinion that confirms to the methods outlined for estimation of carbon stock changes under this methodology can be utilized.

DATA AND PARAMETERS MONITORED

Data /parameter:	A_p
Data unit:	ha
Used in equations:	5
Description:	Total area of sample plots
Source of data:	Recording and archiving of number and size of sample plots.
Measurement procedures (if any):	Monitoring shall be done preferably using a Geographical Information System (GIS), which allows for integrating data from different sources (including GPS coordinates and Remote Sensing data)
Monitoring frequency:	Monitoring must occur for baseline renewal. Where carbon stock enhancement is included, the monitoring frequency can range from 5 to 20 years. In situations where the project adopts a 40-year renewable crediting period, the monitoring frequency can be fixed to coincide with the crediting period.
QA/QC procedures:	The geographic coordinates of the sample plots are established, recorded and archived
Any comment:	

Data /parameter:	A_t
Data unit:	ha
Used in equations:	5
Description:	Total project area
Source of data:	High-resolution aerial imagery (e.g., orthorectified aerial photography or georeferenced remote sensing images).
Measurement procedures (if any):	Monitoring of strata and stand boundaries shall be done preferably using a Geographical Information System (GIS), which allows for integrating data from different sources (including GPS coordinates and Remote Sensing data)
Monitoring frequency:	Monitoring must occur for baseline renewal. Where carbon stock enhancement is included, the monitoring frequency can range from 5 to 20 years. In situations where the project adopts a 40-year renewable crediting period, the monitoring frequency can be fixed to coincide with the crediting period.
QA/QC	The geographic coordinates of the project boundary (and any

procedures:	stratification inside the boundary) are established, recorded and archived
Any comment:	

Data /parameter:	A_{TREE}
Data unit:	ha
Used in equations:	1
Description:	Area of land within the project boundary where living trees are standing at the start of the project activity
Source of data:	High-resolution aerial imagery (e.g., orthorectified aerial photography or georeferenced remote sensing images).
Measurement procedures (if any):	Monitoring of strata and stand boundaries shall be done preferably using a Geographical Information System (GIS), which allows for integrating data from different sources (including GPS coordinates and Remote Sensing data)
Monitoring frequency:	Once at the beginning of the project.
QA/QC procedures:	The geographic coordinates of the project boundary (and any stratification inside the boundary) are established, recorded and archived
Any comment:	

Data /parameter:	BD_{TREE}
Data unit:	ton d.m. ha^{-1}
Used in equations:	1
Description:	Tree biomass density per unit area of the project area (obtained from published literature)
Source of data:	Published data may relate to the project area or to another area similar to the project area. If published data is in terms of volume and not in terms of biomass, or the biomass data does not include the belowground biomass, then transparent and verifiable methods using suitable parameters may be used for calculating the tree biomass per unit area from the available data
Measurement procedures (if any):	

Monitoring frequency:	Once at the beginning of the project.
QA/QC procedures:	
Any comment:	

Data /parameter:	CF_j
Data unit:	ton C ton^{-1} d.m.
Used in equations:	3
Description:	Carbon fraction of biomass for the j^{th} tree species
Source of data:	Values from the literature (e.g. Lamlom and Savidge 2003) shall be used if available, otherwise default value of 0.47 t C t-1 d.m. can be used
Measurement procedures (if any):	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.
Monitoring frequency:	Once for every tree in the project area.
QA/QC procedures:	
Any comment:	

Data /parameter:	CF_{TREE}
Data unit:	ton C ton^{-1} d.m.
Used in equations:	1
Description:	Carbon fraction of dry matter for tree biomass
Source of data:	Values from the literature (e.g. Lamlom and Savidge 2003) shall be used if available, otherwise default value of 0.47 t C t-1 d.m. can be used .
Measurement procedures (if any):	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.
Monitoring frequency:	Once at the beginning of the project.

QA/QC procedures:	
Any comment:	

Data /parameter:	*DBH*
Data unit:	cm
Used in equations:	3, 4
Description:	Diameter at breast height of a tree in cm
Source of data:	Field measurements in sample plots.
Measurement procedures (if any):	Typically measured 1.3 m aboveground using a diameter tape (d-tape) available from arborist or forestry supply dealers, which is designed to read dbh from circumference. The tag number, tree species, and dbh above and below the tag should be recorded along with plot designation information.
Monitoring frequency:	Monitoring must occur for baseline renewal. Where carbon stock enhancement is included, the monitoring frequency can range from 5 to 20 years. In situations where the project adopts a 40-year renewable crediting period, the monitoring frequency can be fixed to coincide with the crediting period.
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 from the IPCC GPG LULUCF 2003, is recommended.
Any comment:	

Data /parameter:	$F_j(X,Y)$
Data unit:	ton d.m $tree^{-1}$
Used in equations:	4
Description:	Allometric equation for species *j* linking measured tree variable(s) to aboveground biomass of living trees
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.

Measurement procedures (if any):	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.
Monitoring frequency:	Monitoring must occur for baseline renewal. Where carbon stock enhancement is included, the monitoring frequency can range from 5 to 20 years. In situations where the project adopts a 40-year renewable crediting period, the monitoring frequency can be fixed to coincide with the crediting period.
QA/QC procedures:	The source data from which equation was derived should be reviewed and confirmed to be representative of the forest type/species and conditions in the project and covering the range of potential independent variable values.
Any comment:	

Data /parameter:	$F_{j(k)}(X,Y)$
Data unit:	ton d.m tree^{-1}
Used in equations:	3
Description:	Allometric equation for species *j* of the k^{th} tree linking measured tree variable(s) to aboveground biomass of living trees
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.
Measurement procedures (if any):	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.
Monitoring frequency:	Once for every tree in the project area.
QA/QC procedures:	The source data from which equation was derived should be reviewed and confirmed to be representative of the forest type/species and conditions in the project and covering the range of potential independent variable values.
Any comment:	

Data /parameter:	*H*
Data unit:	m
Used in	3, 4

equations:	
Description:	Total height of tree
Source of data:	Field measurements in sample plots
Measurement procedures (if any):	Should be carried out using a hagameter, clinometer or similar devise that measures tree height in the field
Monitoring frequency:	Monitoring must occur for baseline renewal. Where carbon stock enhancement is included, the monitoring frequency can range from 5 to 20 years. In situations where the project adopts a 40-year renewable crediting period, the monitoring frequency can be fixed to coincide with the crediting period.
QA/QC procedures:	
Any comment:	

Data /parameter:	R_j
Data unit:	dimensionless
Used in equations:	1, 3, 4
Description:	Root-shoot ratio for tree species or group of species *j.*
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).
Measurement procedures (if any):	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 the AFOLU Guidelines (IPCC 2006), by choosing a climatic zone and forest type that most closely matches the project circumstances.
Monitoring frequency:	Monitoring must occur for baseline renewal. Where carbon stock enhancement is included, the monitoring frequency can range from 5 to 20 years. In situations where the project adopts a 40-year renewable crediting period, the monitoring frequency can be fixed to coincide with the crediting period.
QA/QC	

procedures:	
Any comment:	If the acceptable root-shoot ratios cannot be found, this parameter may be omitted by giving it the value of 0 in the equations where used.