Version Log

Version	Author	Material changes from previous version	Release Date
1.1	Stephen Adu-Bredu Dr Carly Green	Final First Version	28 August 2104

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1 SOURCES

This standard operating procedure (SOP) relates to the latest versions of the following MRV system documentation:

- 001 Estimating Annual Forest Emissions and Removals
- 004 Stratification of Lands
- 008 Estimation of Emissions and Removals from Timber Harvests
- 009 Estimation of Emissions from Extraction of Wood for Fuel
- 010 Estimating Emissions from Fire
- 011 Estimating National and Sub-National Forest Reference Emission Level
- 012 Combining Uncertainty

The following have also informed the development of the SOP:

- GFOI (2013) Integrating remote-sensing and ground-based observations for estimation of emissions and removals of greenhouse gases in forests: Methods and guidance from the Global Forest Observation Initiative: Pub: Group on Earth Observations, Geneva, Switzerland, 2014. ISBN 978-92-990047-4-6
- IPCC Good Practice Guidance for the Land use Land use Change and Forestry (2003)
- Manual 5-4 of the Ghana Forest Preservation Programme
- Pearson T., Walker S. & Brown S. (2005) Sourcebook for Land Use, Land-Use Change and Forestry Projects
- GOFC-GOLD (2013) A sourcebook of methods and procedures for monitoring and reporting anthropogenic greenhouse gas emissions and removals associated with deforestation, gains and losses of carbon stocks in forests remaining forests, and forestation. GOFC-GOLD Report version COP19-1, (GOFC-GOLD Land Cover Project Office, Wageningen University, The Netherlands).
- Henry, M., Besnard, A., Asante, W.A., Eshun, J., Adu-Bredu, S., Valentini, R., Bernoux, M., Saint-André, L. (2010) Wood density, phytomass variations within and among trees, and allometric equations in a tropical rainforest of Africa. Forest Ecology and Management 260: 1375–1388

2 SUMMARY DESCRIPTION

This SOP details the approach to estimate carbon stock and stock change within the above- and belowground biomass and dead wood pools within forestlands in Ghana.

The steps described in this SOP follow the general principles outlined in 2006 IPCC guidelines for biomass estimation.

National specific allometric equations and look-up tables for aboveground, belowground and deadwood pools for all the major ecological zones (six) are applied to develop estimates.

3 DEFINITIONS

Aboveground Biomass

All the biomass above the soil surface in a stand that is alive, including stem, stump, branches, bark, seeds and foliage.

Belowground Biomass

All the biomass of roots that is alive in a stand. Fine roots of less than 2.0 mm diameter are often excluded because these often cannot be distinguished empirically from soil organic matter or litter.

Standing Deadwood

They are standing but dead trees and without foliage. They can be with branches or only the trunk.

Downed Deadwood

Includes all non-living woody biomass lying on the forest floor, which is above 2.0 cm in diameter. The dead wood includes wood lying on the surface, dead roots, and stumps larger

4 APPLICABILITY CONDITIONS

This SOP applies to aboveground and belowground tree biomass and deadwood pools within all the six (6) major ecological zones of Ghana. It is applicable to the estimation of carbon stock changes of both forest and other land-use types.

5 UNFCCC SPECIFIC REQUIREMENTS

UNFCCC decisions on the modalities for National Forest Monitoring systems (NFMS) are documented in Decisions 4/CP.15 and 11/CP.19:

Decision 4/CP.15

- use the most recent IPCC guidance and guidelines, as a basis for estimates;
- establish robust and transparent national forest monitoring systems and, if appropriate, sub-national systems as part of national monitoring systems that:
    - use a combination of remote sensing and ground-based forest carbon inventory approaches
    - provide estimates that are transparent, consistent, as far as possible accurate, and that reduce uncertainties
    - Are transparent and their results are available and suitable for review

Decision 11/CP.19

National forest monitoring systems should:

- be guided by the most recent Intergovernmental Panel on Climate Change guidance and guidelines, as adopted or encouraged by the Conference of the Parties, as appropriate, as a basis for estimating anthropogenic forest-related greenhouse gas emissions by sources, and removals by sinks, forest carbon stocks, and forest carbon stock and forest-area changes;
- provide data and information that are transparent, consistent over time, and are suitable for measuring, reporting and verifying anthropogenic forest-related emissions by sources and removals by sinks, forest carbon stocks, and forest carbon stock and forest-area changes resulting from the implementation of REDD-plus activities
- build upon existing systems, as appropriate;
- enable the assessment of different types of forest in the country, including natural forest;
- be flexible and allow for improvement;
- reflect, as appropriate, the phased approach to that depends on the specific national circumstances, capacities and capabilities of each developing country Party and the level of support received;

6 PROCEDURES

Frequency of measurement for above- and below-ground and deadwood biomass

Measurement of the stocks should be re-estimated from new field measurements after five (5) years.

Part 1: Aboveground biomass: Estimation of carbon stock in aboveground tree biomass

Data from measurements of live trees are carried out in fixed sample plots described in SOP 005 Field Inventory Protocol shall be utilized in the calculation procedures described below.

Step 1: Tree parameter measurement and selection of allometric equation

Data collected in the inventory at the plot level includes ecozone classification, diameter at breast height (d), height (h) and species (as a proxy for wood density).

The most appropriate allometric equation for the ecological zone is selected for the determination of the aboveground mass of the tree. The relevant allometric equations are listed in (Appendix 1 of this standard operating procedure and SOP 004 Stratification of Lands also provides an ecozone/allometic equation translation. A summary of the stratification of equations is as follows:

- Wet zone comprises of Wet and Moist ecological zone
- Moist zone comprises of Moist Semi-deciduous and Upland evergreen ecological zones
- Dry zone comprises of Dry Semi-deciduous and Savannah ecological zones

The equation for teak (Tectona grandis) is used for the plantations since over 70% of the plantations in Ghana is estimated comprise primarily of teak.

Step 2: Aboveground biomass of the sample plots

Estimate aboveground biomass of the sample plot by calculating the mass of each individual tree in the plot and then sum up the mass of the individual trees in the plot, dividing the carbon stock in the plot by the area of the plot and then multiplying by the CO_2 conversion factor (i.e.44/12) to get an estimate of tonnes CO_2-e per hectare.

$$CABPlot = \frac{\sum_{t \in Trees}[f_{Above}(z \quad , \rho_t, d_t)]}{A} \times \frac{CF}{1000} \times \frac{44}{12} \tag{1}$$

where

CABPlot	Estimate of carbon stock of aboveground biomass per unit area for a plot; t CO_2-e ha^{-1}
$f_{Above}(z \quad , \rho_t, d_t)$	Allometric equation for aboveground mass in trees in ecozone of the plot (z) linking measured tree parameters, wood density (ρ) and diameter at breast height (d), to aboveground mass of trees; t dm
$t \in$ Tress	Each tree (t) from the set of trees (Trees) in the same plot;
CF	Carbon content (fraction) of trees, default value of 0.47;
$\frac{44}{12}$	Ratio of molecular weight of CO_2 to carbon; CO_2 C^{-1}
A	Area of the plot; ha

Step 3: Calculation of mean carbon stock of aboveground biomass of each stratum

The mean carbon stock in each stratum is estimated by mean of the carbon stock in each plot. (Equation 2).

$$CAB = \frac{\sum_{p \in Plots} CABPlot_p}{N_{Plots}} \tag{2}$$

where

CAB	Mean carbon stock of aboveground biomass of all the plots in the same ecozone and land use; t CO_2-e ha^{-1}
$CABPlot_p$	Carbon stock of aboveground biomass in each sample plot (p) from the set of plots (Plots) in the same ecozone and land use; t CO_2-e ha^{-1}
N_{Plots}	The number of plots in the same ecozone and land use; Dimensionless
$p \in$ Plots	Each plot (p) from the set of plots (Plots) in the same ecozone and land use;

The standard deviation for each stratum is used in the estimation of uncertainty and is calculated according to Equation 3.

$$SD(CAB) \quad = \sqrt{\frac{\sum_{p \in Plots} \left[\left(CABPlot_p - CAB \quad \right)^2 \right]}{N_{Plots} - 1}} \tag{3}$$

where

$\mathrm{SD(CAB)}$	Standard deviation of the carbon stock of aboveground biomass of all the plots in the same ecozone and land use; $\mathrm{t\ CO_2\text{-}e\ ha^{-1}}$
$\mathrm{CABPlot_p}$	Carbon stock of aboveground biomass in each sample plot (p) from the set of plots (Plots) in the same ecozone and land use; $\mathrm{t\ CO_2\text{-}e\ ha^{-1}}$
CAB	Mean carbon stock of aboveground biomass of all the plots in the same ecozone and land use; $\mathrm{t\ CO_2\text{-}e\ ha^{-1}}$
$\mathrm{N_{Plots}}$	The number of plots in the same ecozone and land use; Dimensionless
$\mathrm{p \in Plots}$	Each plot (p) from the set of plots (Plots) in the same ecozone and land use;

The percentage uncertainty is then estimated for the 95% confidence interval according to Equation 4

$$U(CAB) \quad = \left(\frac{2 \times SD(CAB)}{CAB} \right) + 100 \tag{4}$$

where

$U(CAB)$	Percentage uncertainty of the carbon stock of aboveground biomass of all the plots in the same ecozone and land use; Percentage
$\mathrm{SD(CAB)}$	Standard deviation of the carbon stock of aboveground biomass of all the plots in the same ecozone and land use; $\mathrm{t\ CO_2\text{-}e\ ha^{-1}}$
CAB	Mean carbon stock of aboveground biomass of all the plots in the same ecozone and land use; $\mathrm{t\ CO_2\text{-}e\ ha^{-1}}$

Part 2: Estimation of carbon stock in belowground tree biomass

Step 1: Tree parameter measurement and selection of allometric equation

The belowground biomass per unit area is estimated based on measurement of aboveground parameters on the sample plots. The most appropriate equation for the ecological zone is selected (Appendix 1) as described for the aboveground biomass. This must be consistent with the ecological zone selected to estimate belowground biomass in the same plot.

Sum up the mass of the individual trees in the sample plots to estimate the belowground biomass (Equation 5).

$$CBBPlot = \frac{\sum_{t \in Trees} [f_{Below}(z \quad, \rho_t, d_t)]}{A} \times \frac{CF}{1000} \times \frac{44}{12} \qquad (5)$$

where

CBBPlot	Estimate of carbon stock of belowground biomass per unit area for a plot; t CO_2-e ha^{-1}
$f_{Below}(z \quad, \rho_t, d_t)$	Allometric equation for belowground mass in trees in ecozone of the plot (z) linking measured tree parameters, wood density (ρ) and diameter at breast height (d), to belowground mass of trees; t d.m.
$t \in Trees$	Each tree (t) from the set of trees (Trees) in the same plot;
CF	Carbon content (fraction) of trees, default value of 0.47;
$\frac{44}{12}$	Ratio of molecular weight of CO_2 to carbon; CO_2 C^{-1}
A	Area of the plot; ha

Step 2: Calculate the mean carbon stock of belowground biomass of each stratum

The mean carbon stock in each stratum is estimated by mean of the carbon stock in each plot (Equation 6).

$$CBB = \frac{\sum_{p \in Plots} CBBPlot_p}{N_{Plots}} \qquad (6)$$

where

CBB	Mean carbon stock of belowground biomass of all the plots in the same ecozone and land use; $t\ CO_2\text{-e}\ ha^{-1}$
$CBBPlot_p$	Carbon stock of belowground biomass in each sample plot (p) from the set of plots (Plots) in the same ecozone and land use; $t\ CO_2\text{-e}\ ha^{-1}$
N_{Plots}	The number of plots in the same ecozone and land use; Dimensionless
$p \in Plots$	Each plot (p) from the set of plots (Plots) in the same ecozone and land use;

Step 3: Calculate the uncertainty associated with belowground biomass

The standard deviation for each stratum is used in the estimation of uncertainty and is calculated according to Equation 7.

$$SD(CBB) = \sqrt{\frac{\sum_{p \in Plots}\left[\left(CBBPlot_p - CBB\right)^2\right]}{N_{Plots} - 1}} \quad (7)$$

where

$SD(CBB)$	Standard deviation of the carbon stock of belowground biomass of all the plots in the same ecozone and land use; $t\ CO_2\text{-e}\ ha^{-1}$
$CBBPlot_p$	Carbon stock of belowground biomass in each sample plot (p) from the set of plots (Plots) in the same ecozone and land use; $t\ CO_2\text{-e}\ ha^{-1}$
CBB	Mean carbon stock of belowground biomass of all the plots in the same ecozone and land use; $t\ CO_2\text{-e}\ ha^{-1}$
N_{Plots}	The number of plots in the same ecozone and land use; Dimensionless
$p \in Plots$	Each plot (p) from the set of plots (Plots) in the same ecozone and land use;

The percentage uncertainty is then estimated for the 95% confidence interval according to Equation 8

$$U(CBB) = \left(\frac{2 \times SD(CBB)}{CBB}\right) + 100 \quad (8)$$

where

$U(CBB)$	Percentage uncertainty of the carbon stock of belowground biomass of all the plots in the same ecozone and land use; Percentage
$SD(CBB)$	Standard deviation of the carbon stock of belowground biomass of all the plots in the same ecozone and land use; $t\ CO_2\text{-}e\ ha^{-1}$
CBB	Mean carbon stock of belowground biomass of all the plots in the same ecozone and land use; $t\ CO_2\text{-}e\ ha^{-1}$

Part 4: Estimating Carbon Stock in Deadwood

The deadwood shall be differentiated into standing and downed deadwood. The methods for measurements of the two components are described in the standard operating procedure 005 Field Inventory Protocol shall be utilized in the calculation procedures described below.

Part 4.1: Mass of deadwood

Step 1: Estimation of mass of standing deadwood

The state of decomposition of the standing dead wood shall be classified and recorded into two decomposition classes namely:-

1. No outward signs of decomposition - Trees with branches and twigs and resembles a live tree (except for leaves);
2. Signs of decomposition – Trees (in addition to loss of foliage), with loss twigs and branches.

Step 1.1: Decomposition Class 1

For decomposition Class 1, which has no outward sign of decomposition, the wood density is assumed to be comparable to that of live tree. The diameter at breast height (d) as with live tree and the appropriate allometric equation for live trees shall be used to estimate the mass of trees. The foliage mass shall then be subtracted from it based on research from Henry et. al. (2010).

The mass of standing dead trees for decomposition Class 1 is estimated as:

$$MSDTC1Plot = \sum_{t \in Class\ 1\ Standing\ Dead\ Trees} \left[f_{Above}(z\ \ , \rho_t, dbh_t) \times \frac{0.9911}{A} \right] \tag{9}$$

where

$MSDTC1Plot$	Estimate of mass of standing dead trees for decomposition class 1 per unit area for a plot; kg d.m. ha^{-1}
$f_{Above}(z\ \ , \rho_t, dbh_t)$	Allometric equation for aboveground mass in trees in ecozone of the plot (z) linking measured tree parameters, wood density (ρ) and diameter at breast height (dbh), to belowground mass of trees; t dm
t ∈ Class 1 Standing Dead Trees	Each class 1 standing dead tree (t) from the set of standing dead trees (Trees) in the same plot;
A	Area of the plot; ha
0.9911	Proportion of aboveground tree mass excluding that of foliage (calculated as 1-0.0089);

Step 1.2: Decomposition Class 2

For decomposition Class 2, where it is not clear what proportion the original mass of the tree has been lost, it is conservative to regard only the bole (trunk) of the tree (Pearson et. al. (2005)). The diameter at breast height (dbh) is measured as with live tree, and regarded as basal diameter, the height measured with LaserAce and the top diameter (td) measured with either relascope or LaserAce. The volume of the trunk is calculated as a truncated cone.

The mass of standing deadwood for decomposition Class 2 is therefore estimated as:

$$MSDTC2Plot = \sum_{t \in Class\ 2\ Standing\ Dead\ Trees} \left[\frac{\pi}{12 \times A} \times h_t \times (dbh_t^2 + (dbh_t \times td_t) + td_t^2) \times \rho_t \right] \tag{10}$$

where

$MSDTC2Plot$	Estimate of mass of standing dead trees for decomposition class 2 per unit area for a plot; kg d.m. ha^{-1}
h_t	Height of the class 2 standing dead tree (t); m
dbh_t	Diameter at breast height of the class 2 standing dead tree (t); cm
td_t	Top diameter of the class 2 standing dead tree (t); cm

dc_t	Mean wood density of dead wood in the class 2 standing dead tree (t) density class (dc) – sound (1), intermediate (2), and rotten (3); g d.m. cm^{-3}
t ∈ Class 2 Standing Dead Trees	Each class 2 standing dead tree (t) from the set of standing dead trees (Trees) in the same plot;
A	Area of the plot; ha

The volume of the stump shall be calculated as that of a cylinder and converted to mass by multiplying by wood density:

$$MSPlot = \sum_{t \in Class\ 2\ Stump} \left[\frac{\pi}{4 \times A} \times HStump_t \times DStump_t^2 \times dc_t\right] \qquad (11)$$

where

$MSPlot$	Estimate of mass of stumps for decomposition class 2 per unit area for a plot; kg d.m. ha^{-1}
$\mathrm{hstump_t}$	Height of the class 2 stump (t); m
$\mathrm{dstump_t}$	Diameter at top of the class 2 stump (t); cm
dc_t	Mean wood density of dead wood in the class 2 stump (t) density class (dc) – sound (1), intermediate (2), and rotten (3); g d.m. cm^{-3}
t ∈ Class 2 Stump	Each class 2 stump (t) from the set of stumps (Trees) in the same plot;
A	Area of the plot; ha

Step 2: Estimation of mass of downed deadwood

The approach to the collection downed dead wood data is described in the standard operating procedure 005 Field Inventory Protocol shall be utilized in the calculation procedures described below. The downed dead wood is classified into sound, intermediate and rotten density classes.

Estimate mass of downed dead wood per unit area as (cf. van Wagner, 1982):

$$MDPlot = \sum_{t \in Downed\ Deadwood} \left[\frac{\pi^2}{8 \times L} \times ddd_t^2 \times dc_t \right]$$

(12)

where

$MDPlot$	Estimate of mass of downed deadwood per unit area for a plot; kg d.m. ha^{-1}
ddd_t	Diameter of piece of deadwood (t) along the transect; cm
dc_t	Mean wood density of dead wood in the downed deadwood (t) density class (dc) – sound (1), intermediate (2), and rotten (3); g d.m. cm^{-3}
L_t	Length of the transect (100m); m
$t \in$ Downed Deadwood	Each class 2 standing dead tree (t) from the set of standing dead trees (Trees) in the same plot;
A	Area of the plot; ha

Part 4.2: Combining estimates of deadwood

Step 1: Combining estimates of deadwood for a plot

Carbon stock of the deadwood pool in a plot is calculated as the sum of standing dead trees and downed deadwood components, converted to carbon dioxide equivalent (Equation 28).

$$CDWPlot = (MSDTC1Plot + MSDTC2Plot + MSPlot + MDPlot) \times \frac{CF}{1000} \times \frac{44}{12}$$

(13)

where

CDWPlot	Carbon stock of deadwood in a plot; t CO_2-e ha^{-1}
$MSDTC1Plot$	Estimate of mass of standing dead trees for decomposition class 1 per unit area for a plot; kg d.m. ha^{-1}
$MSDTC2Plot$	Estimate of mass of standing dead trees for decomposition class 2 per unit area for a plot; kg d.m. ha^{-1}
$MSPlot$	Estimate of mass of stumps for decomposition class 2 per unit area for a plot; kg d.m. ha^{-1}
$MDPlot$	Estimate of mass of downed deadwood per unit area for a plot; kg d.m. ha^{-1}

CF	Carbon fraction of dried matter in deadwood;
$\frac{44}{12}$	Ratio of molecular weight of CO_2 to carbon; CO_2 C^{-1}

Step 2: Calculate the mean carbon stock of deadwood of each stratum

The mean carbon stock in each stratum is estimated by mean of the carbon stock of the plots in the stratum (Equation 6).

$$CDW = \frac{\sum_{p \in Plots} CDWPlot_p}{N_{Plots}} \tag{14}$$

where

CDW	Mean carbon stock of deadwood of all the plots in the same ecozone and land use; t CO_2-e ha^{-1}
$CDWPlot_p$	Carbon stock of belowground biomass in each sample plot (p) from the set of plots (Plots) in the same ecozone and land use; t CO_2-e ha^{-1}
N_{Plots}	The number of plots in the same ecozone and land use; Dimensionless
$p \in Plots$	Each plot (p) from the set of plots (Plots) in the same ecozone and land use;

Step 3: Calculate the uncertainty associated with deadwood

The standard deviation for each stratum is used in the estimation of uncertainty and is calculated according to Equation 7.

$$SD(CDW) = \sqrt{\frac{\sum_{p \in Plots} \left[\left(CDWPlot_p - CDW \right)^2 \right]}{N_{Plots} - 1}} \tag{15}$$

where

$\mathrm{SD(CDW)}$	Standard deviation of the carbon stock of deadwood of all the plots in the same ecozone and land use; $\mathrm{t\ CO_2\text{-}e\ ha^{-1}}$
$\mathrm{CDWPlot_p}$	Carbon stock of deadwood in each sample plot (p) from the set of plots (Plots) in the same ecozone and land use; $\mathrm{t\ CO_2\text{-}e\ ha^{-1}}$
CDW	Mean carbon stock of deadwood of all the plots in the same ecozone and land use; $\mathrm{t\ CO_2\text{-}e\ ha^{-1}}$
$\mathrm{N_{Plots}}$	The number of plots in the same ecozone and land use; Dimensionless
$\mathrm{p \in Plots}$	Each plot (p) from the set of plots (Plots) in the same ecozone and land use;

The percentage uncertainty is then estimated for the 95% confidence interval according to Equation 8

$$U(CDW) \quad = \left(\frac{2 \times SD(CDW)}{CDW}\right) + 100 \tag{16}$$

where

$U(CDW)$	Percentage uncertainty of the carbon stock of deadwood of all the plots in the same ecozone and land use; Percentage
$\mathrm{SD(CDW)}$	Standard deviation of the carbon stock of deadwood of all the plots in the same ecozone and land use; $\mathrm{t\ CO_2\text{-}e\ ha^{-1}}$
CDW	Mean carbon stock of deadwood of all the plots in the same ecozone and land use; $\mathrm{t\ CO_2\text{-}e\ ha^{-1}}$

7 DATA AND PARAMETERS

Data and Parameters Available

Data and parameters that will not change year to year (i.e. default values used in the estimation) as well as calculated values from any equations presented in this standard operating procedure.

Data / Parameter:	CABPlot
Data unit	t CO_2-e ha^{-1}
Description	Estimate of carbon stock of aboveground biomass per unit area for a plot
Equations	1
Source of data	Calculated
Value applied	NA
Justification of choice of data or description of measurement methods and procedures applied	NA
Purpose of Data	
Comments	

Data / Parameter:	$f_{Above}(z \quad , \rho_t, dbh_t)$
Data unit	t dm
Description	Allometric equation for aboveground mass in trees in ecozone of the plot (z) linking measured tree parameters, wood density (ρ) and diameter at breast height (d), to aboveground mass of trees
Equations	1,9
Source of data	FPP Report, FPP manual 5.4, 2013
Value applied	Varied equations based on ecoszone
Justification of choice of data or description of measurement methods and procedures applied	Ecozone
Purpose of Data	
Comments	

Data / Parameter:	CF

Data unit	g g-1 d.m.
Description	Carbon content (fraction)
Equations	1,5,13
Source of data	For the trees, carbon fraction (carbon content) value of 0.47 which was derived as an average from the destructive sampling data (FPP Report, FPP manual 5.4, 2013)
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	
Purpose of Data	Convert dry matter into carbon
Comments	

Data / Parameter:	CAB
Data unit	t CO_2-e ha^{-1}
Description	Mean carbon stock of aboveground biomass of all the plots in the same ecozone and land use
Equations	2,3,4
Source of data	Calculated
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	
Purpose of Data	
Comments	

Data / Parameter:	$\mathrm{SD}(\mathrm{CAB})$
Data unit	t CO_2-e ha^{-1}
Description	Standard deviation of the carbon stock of aboveground biomass of all the plots in the same ecozone and land use
Equations	3,4
Source of data	Calculated
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	
Purpose of Data	
Comments	

Data / Parameter:	$U(CAB)$
Data unit	Percentage
Description	Percentage uncertainty of the carbon stock of aboveground biomass of all the plots in the same ecozone and land use
Equations	4
Source of data	Calculated
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	
Purpose of Data	
Comments	

Data / Parameter:	CBBPlot
Data unit	t CO_2-e ha^{-1}
Description	Estimate of carbon stock of belowground biomass per unit area for a plot
Equations	5,6,7
Source of data	Calculated
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	
Purpose of Data	
Comments	

Data / Parameter:	$f_{Below}(z\quad, \rho_t, dbh_t)$
Data unit	t d.m.
Description	Allometric equation for belowground mass in trees in ecozone of the plot (z) linking measured tree parameters, wood density (ρ) and diameter at breast height (d), to belowground mass of trees
Equations	5
Source of data	FPP Report, FPP manual 5.4, 2013
Value applied	Varied equations based on ecoszone
Justification of choice of data or description of measurement methods and procedures applied	Ecozone
Purpose of Data	
Comments	

Data / Parameter:	CBB
Data unit	t CO_2-e ha^{-1}
Description	Mean carbon stock of belowground biomass of all the plots in the same ecozone and land use
Equations	6,7,8
Source of data	Calculated
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	
Purpose of Data	
Comments	

Data / Parameter:	$SD(CBB)$
Data unit	t CO_2-e ha^{-1}
Description	Standard deviation of the carbon stock of belowground biomass of all the plots in the same ecozone and land use
Equations	7,8
Source of data	Calculated
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	
Purpose of Data	
Comments	

Data / Parameter:	$U(CBB)$
Data unit	Percentage
Description	Percentage uncertainty of the carbon stock of belowground biomass of all the plots in the same ecozone and land use
Equations	8
Source of data	Calculated
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	
Purpose of Data	
Comments	

Data / Parameter:	$MSDTC1Plot$
Data unit	kg d.m. ha^{-1}
Description	Estimate of mass of standing dead trees for decomposition class 1 per unit area for a plot
Equations	9,13
Source of data	Calculated
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	
Purpose of Data	
Comments	

Data / Parameter:	$MSDTC2Plot$
Data unit	kg d.m. ha^{-1}
Description	Estimate of mass of standing dead trees for decomposition class 2 per unit area for a plot
Equations	10,13
Source of data	Calculated
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	
Purpose of Data	
Comments	

Data / Parameter:	$MSPlot$
Data unit	kg d.m. ha^{-1}
Description	Estimate of mass of stumps for decomposition class 2 per unit area for a plot
Equations	11,13
Source of data	Calculated
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	
Purpose of Data	
Comments	

Data / Parameter:	$MDPlot$
Data unit	kg d.m. ha^{-1}
Description	Estimate of mass of downed deadwood per unit area for a plot
Equations	12,13
Source of data	Calculated
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	
Purpose of Data	
Comments	

Data / Parameter:	L_t
Data unit	m
Description	Length of the transect (100m)
Equations	12
Source of data	Field Inventory SOP005
Value applied	100m
Justification of choice of data or description of measurement methods and procedures applied	The line intersect method shall be used sample downed dead wood (van Wagner, 1982; Harmon & Sexton, 1996). Two 50 m lines shall be laid out bisecting the preexisting sample plots for live biomass estimation. only diameter of dead wood greater than 10 cm diameter intersecting the lines are measured by caliper
Purpose of Data	Transect for measuring and recording deadwood
Comments	

Data / Parameter:	$CDWPlot$
Data unit	$t\ CO_2\text{-}e\ ha^{-1}$
Description	Carbon stock of deadwood in a plot
Equations	13,14,15
Source of data	Calculated
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	
Purpose of Data	
Comments	

Data / Parameter:	CDW
Data unit	$t\ CO_2\text{-}e\ ha^{-1}$
Description	Mean carbon stock of deadwood of all the plots in the same ecozone and land use
Equations	14,15,16
Source of data	Calculated
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	
Purpose of Data	
Comments	

Data / Parameter:	$SD(CDW)$
Data unit	t CO_2-e ha^{-1}
Description	Standard deviation of the carbon stock of deadwood of all the plots in the same ecozone and land use
Equations	15,16
Source of data	Calculated
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	
Purpose of Data	
Comments	

Data / Parameter:	$U(CDW)$
Data unit	Percentage
Description	Percentage uncertainty of the carbon stock of deadwood of all the plots in the same ecozone and land use
Equations	16
Source of data	Calculated
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	
Purpose of Data	
Comments	

Data and Parameters Monitored

Data and parameters that will be monitored (i.e. that will change between reporting years, such as area deforested).

Data / Parameter:	A
Data unit:	ha
Description:	Area of the plot
Equations:	1,5,9,10,11,12
Source of data:	Field Inventory SOP 005
Frequency of monitoring/recording:	At the time of resurvey of the field inventory
Purpose of Data:	To convert standing stock into an areal basis
Comments:	Refer to SOP 005 for details on the field inventory protocol

Data / Parameter:	N_{Plots}
Data unit:	Dimensionless
Description:	The number of plots in the same ecozone and land use
Equations:	2,3,6,7,14,15
Source of data:	Field Inventory SOP 005
Frequency of monitoring/recording:	At the time of resurvey of the field inventory
Purpose of Data:	To stratify the forest by ecozone and forest type
Comments:	

Data / Parameter:	ρ_t
Data unit	N/A
Description	Wood density for each tree species measured for use in the allometric equations
Equations	1,5,9
Source of data	Inventory data collected by qualified botanists. The source of data is the national inventory plots, about 100 wood densities have been established under the FPP. Some additional species wood densities were acquired through literature
Value applied	Multiple values
Frequency of monitoring/recording	As often as inventories are conducted
Purpose of Data	The purpose of collecting tree species is to allocate the wood density to the tree allometric equation.
Comments	Data on savannah zone was restricted to only the southern savannah and did not cover the northern savannah under the FPP

Data / Parameter	dbh_t
Data unit	cm
Description	Diameter of tree at breast height
Equations	1,5,9
Source of data	Field measurement from inventory
Value Applied	Multiple values
Frequency of monitoring/recording	
Purpose of data	
Comments	The diameter at breast height is measured at 1.3 m above ground level using diameter tape graduated in cm. In the case of buttress trees that exceeds 1.3 m, the point of measurement is taken 0.5 m above the point of convergence.

Data / Parameter:	h_t
Data unit:	m
Description:	Height of the class 2 standing dead tree (t)
Equations:	10
Source of data:	Field inventory as described in SOP 005
Frequency of monitoring/recording:	As often as inventories are conducted
Purpose of Data:	
Comments:	

Data / Parameter:	dbh_t
Data unit:	cm
Description:	Diameter at breast height of the class 2 standing dead tree (t)
Equations:	10
Source of data:	Field inventory as described in SOP 005
Frequency of monitoring/recording:	As often as inventories are conducted
Purpose of Data:	
Comments:	

Data / Parameter:	td_t
Data unit:	cm
Description:	Top diameter of the class 2 standing dead tree (t)
Equations:	10
Source of data:	Field inventory as described in SOP 005
Frequency of monitoring/recording:	As often as inventories are conducted
Purpose of Data:	
Comments:	

Data / Parameter:	dc_t
Data unit:	g d.m. cm^{-3}
Description:	Mean wood density of dead wood in the class 2 standing dead tree (t) density class (dc) – sound (1), intermediate (2), and rotten (3)
Equations:	10
Source of data:	Species specific wood density for Ghana. Where not available apply a regionally relevant value from the global wood density database.
Frequency of monitoring/recording:	As often as inventories are conducted
Purpose of Data:	
Comments:	

Data / Parameter:	$hstump_t$
Data unit:	m
Description:	Height of the class 2 stump (t)
Equations:	11
Source of data:	Field inventory as described in SOP 005
Frequency of monitoring/recording:	As often as inventories are conducted
Purpose of Data:	
Comments:	

Data / Parameter:	$dstump_t$
Data unit:	cm
Description:	Diameter at top of the class 2 stump (t)
Equations:	11
Source of data:	Calculated
Frequency of monitoring/recording:	Field inventory as described in SOP 005
Purpose of Data:	As often as inventories are conducted
Comments:	

Data / Parameter:	dc_t
Data unit:	g d.m. cm^{-3}
Description:	Mean wood density of dead wood in the class 2 stump (t) density class (dc) – sound (1), intermediate (2), and rotten (3)
Equations:	11
Source of data:	Calculated
Frequency of monitoring/recording:	Field inventory as described in SOP 005
Purpose of Data:	As often as inventories are conducted
Comments:	

Data / Parameter:	ddd_t
Data unit:	cm
Description:	Diameter of piece of deadwood (t) along the transect
Equations:	12
Source of data:	Calculated
Frequency of monitoring/recording:	Field inventory as described in SOP 005
Purpose of Data:	As often as inventories are conducted
Comments:	

Data / Parameter:	dc_t
Data unit:	g d.m. cm^{-3}
Description:	Mean wood density of dead wood in the downed deadwood (t) density class (dc) – sound (1), intermediate (2), and rotten (3)
Equations:	12
Source of data:	Calculated
Frequency of monitoring/recording:	Field inventory as described in SOP 005
Purpose of Data:	As often as inventories are conducted
Comments:	

8 QUALITY ASSURANCE AND QUALITY CONTROL

8.1: Data source

- The data will be provided by the RMSC following the inventory quality assurance and quality control.
- Data and information generated shall be documented, archived and reported by the RMSC. This is to facilitate the review and assessment of inventory estimates.
- The following shall be checked:
    - Transcription errors in data input and references
    - Calculations are correctly carried out
    - Parameters and units are correctly recorded and that appropriate conversion factors are used.
    - Integrity of database files
    - Consistency in data among categories
    - The movement of inventory data among processing steps is correct.
    - Uncertainties in emissions and removals are estimated and calculated correctly
    - Time series consistency
    - Completeness
    - Trend
    - Review of internal documentation and archiving.

8.2: Independent reviewer

- The calculation and estimates generated will be independently reviewed by a qualified institution. The Forestry Research Institute of Ghana of the Council for Scientific and Industrial Research (CSIR-FORIG) is the qualified institution that shall be engaged.
- The independent reviewer is to ensure that;
    - Data quality objectives were met
    - The inventory represents the best possible estimates based on the SOP and data availability.
- The results of expert peer review and the response of the inventory compiler to those findings shall be documented. The findings and recommendations shall provide the basis for continuous improvement.

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10 GLOSSARY

GFOI – Global Forest Observation Initiative

HFZ – High Forest Zone

IPCC – Intergovernmental Panel on Climate Change

UNFCCC – United Nations Framework Convention on Climate Change

APPENDIX 1: ALLOMETRIC EQUATIONS

For teak, the above ground phytomass is to be estimated from the model of Adu-Bredu (Unpublished) on the basis of 14 destructively sampled trees, with age ranging from six to twenty nine years as;

$$M_{ag} = 0.2480\ (\rho\ d_{bh}^{2})^{1.1529} \qquad (R^2 = 0.9929)$$

Model	Ecological zone								
	Dry			Moist			Wet		
Aboveground	a	b	R2	a	b	R2	a	b	R2
Mag=a***ρ***(d^2)b	0.734	1.055	0.871	0.0124	1.542	0.9739	0.041	1.433	0.9691
Belowground	a	b	R2	a	b	R2	a	b	R2
Mbg=a***ρ***(d^2)b	3.6102	0.4509	0.4899	0.0518	1.214	0.75623	0.2883	0.9379	0.9595
Mbg=a(Mag)b	1.582	0.6356	0.6862	2.169	0.6098	0.49944	0.4533	0.8469	0.9528

Legend: ρ = wood density; d = diameter at breast height; Mag = Aboveground mass; Mbg = Belowground mass

Source: Developed for FPP 2013