BIOREDD+ Program

DELIVERABLE 12: ESTIMATES OF ALL CARBON POOLS IN PROJECT AREAS

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1. Statement of task 12

Estimates of all identified carbon pools within the project scope (aboveground, belowground, dead, litter, soil) derived from IPCC guidelines, and regional field inventory over the project areas. The includes the GIS raster files of carbon pools at 1-ha spatial resolution over all four project nodes and the buffer zones. Results on carbon estimates must be within the 10% error threshold at 95% confidence interval required by the VCS. This report will only provide the estimation of carbon pools and the uncertainty analysis. All maps and GIS raster files will be delivered with Task 10.

2. Background

To estimate the emission factors for deforestation and degradation the following carbon pools will be included in the forest carbon monitoring systems (FCMS) and future MRV systems: aboveground biomass, belowground biomass, lying and standing dead wood, litter and soil. For the soil pool, the emissions will be based on estimating the loss in the reference soil carbon pool using factors that vary due to the land use, management practice, and any inputs (IPCC 2006 GL)—this is all captured in an equation that provides an estimate of the emissions per unit area per year in the following sections. Here, we include emissions from deforestation as the conversion of the forest (intact, degraded, secondary) to nonforest land use (grasslands, croplands, settlements, other) and degradation as the conversion of intact forest to degraded forests. Emission factors are related to the carbon stock in the selected pools for each type of land use and land cover change. In this reports, the details for estimating the values of the selected pools that are used for calculating the emission factors are given.

3. Data Sources & Processing

Data sources and any steps for processing the data for calculating the carbon pools are summarized as follows:

1. Project plot-based measurements: Plot-based measurements within the LULC class or forest stratum that are used for both calibrating and validating remote sensing sampling unit data (RSSU) and measurements of carbon pools. Overall, we have the following number of plots to evaluate the lidar model: 1) 15 1-ha permanent plots within the lidar transects. We divided each plot to four 0.25 ha plots to increase the number of plots for calibration and validation. This resulted to 60 plots at 0.25ha, 2) we have 15 sets of satellite plots falling in the lidar transects with each set having 8 satellite plots at 0.25 ha for a total number of 120 with 109 plots accurately located in lidar images, and 3) we collected 45 plots in 0.25 ha systematically within one lidar transect. Overall, we had 214 plots at 0.25 ha in size to develop and test the accuracy of lidar predictive model. These plots were located in different forest types as indicated by the field observation

and comparison with remote sensing data. Table 7.1. Number of plots established in the BioREDD project and used in developing and testing the accuracy of Lidar biomass model.

Table 3.1. Number of plots established in the BioREDD project and used in developing and testing the accuracy of Lidar biomass model.

Forest inventory plots	**Size and shape**	**Number of plots in Lidar transects**	**Number of plots at 0.25 ha size**	**Number of 0.25 ha in lidar transects**
16 permanent plots	1-ha, 100 m x 100 m	15	64	60
16 cluster of satellite plots	0.25 ha (50 m x 50 m)	15	128	109
1 set of systematic sampling plots	0.25 ha (50 m x 50 m)	45	45	45
Total	**-**	**75**	**237**	**214**

2. We followed the VM0006 methodology in allocating the plots and biomass values with the LULC classes. If degradation is not included, the LULC class of a specific biomass plot was determined based on the LULC map that is closest in time to the time of measurement of the biomass plot. Here, we used the LULC map developed for the project and included satellite observations from 2012. Although, the plot data were collected in 2013, the LULC class associated with the plot was also verified by the field crew and examining the lidar and aerial photography imagery acquired in 2013. In case multiple measurements are available for one permanent biomass inventory plot, only the most recent value of the carbon stock density was used. We did not multiple measurements for each plot but had several plots within each LULC class that were used to create mean and variance of biomass for each class as described in previous reports (Report 8 and 9). Since degradation is included, the aggregations of non-forest LULC classes follow the procedures as if degradation is not included. However, biomass inventory plots located in forest area are assigned the appropriate forest stratum or LULC class using the forest stratification model or the map developed and reported earlier. In the BioREDD project, the average carbon stock density on both forest and non-forest LULC classes must be assessed using non-permanent sampling plots. Alternatively, conservative defaults gathered from scientific literature may be used to quantify the carbon stock density on non-forest land. The applicability of these default values must be confirmed by the validator. Within a LULC class or forest stratum, the location of sample plots is selected randomly. The randomization was done *ex-ante* by a computer program as in the GIS NOAA tools. All random points fall in lidar image data and therefore will avoid any subjective choice of plot locations for both carbon calculation and calibrating and validating the remote sensing data. For each sample plot, we recorded the observed LULC class and forest type, and also estimated forest

canopy closure from lidar and field survey if such information were available by the ground crew.

1. For developing local allometric equations for trees have been harvested from different locations representing the species and diameter and height classes for the forests of the region. The allometric equations were also separated for three types of forests as in terra firme (Colinas), flooded forests (Guandal) and mangrove (manglar). These equations were used to calculate the forest above ground biomass from field data that in turn were used to calibrate and validate remote sensing estimates of forest biomass. For other carbon pools direct measurements and/or existing allometric models were used.
2. Remote sensing based estimates: We used the airborne lidar data random samples in forest strata and LULC over the BioREDD region to estimate the above ground forest biomass. These estimates of forest above ground biomass were also used to extrapolate other carbon pools over the BioREDD regions by developing simple models or ratios between the aboveground carbon pool and other components.
3. Literature based estimates. Among carbon pools, we did not measure the above-ground non-tree carbon biomass that are often done from destructive sampling approaches. Alternatively, we used existing data from literature to estimate the carbon pool in non-tree vegetation and liter and reported it in our calculation. Soil carbon was also not measured during the BioREDD project. However, we used the soil map and the carbon attributes available for the region to estimate the soil carbon pool and its uncertainty.

4. Definitions

The primary focus of this report is to document the calculation and accuracy of all carbon pools in BioREDD regions. All calculations are performed to meet the requirements outlined in the VM0006 methodology. The carbon pools are defined as follows:

1. **Aboveground organic matter of trees AGT** (defined as OM_{AGT} in VM0006): The aboveground organic matter determined by using measurement of tree structure such as diameter (D), height (H) and wood density of all trees using the appropriate cutoff D specified in the allometric equation (e.g., $D \geq 10$ cm) within the sampling plot. The allometric equation used to calculate the AGT is developed locally for the BioREDD project and remain fixed during a baseline validation period.
2. **Aboveground non-tree organic matter AGNT:** The aboveground non-tree vegetation includes all saplings and trees below the minimum tree size measured in the tree biomass pool, all shrubs, and all other non-herbaceous live vegetation. During the BioREDD project, the components of this pool were not measured. Alternatively, we have used the aboveground organic matter estimated using default values from the IPCC default values by following appropriate tool as the latest version of CDM Tool *Estimation of carbon stocks and change in carbon stocks of trees and shrubs in AR CDM project activities.*
3. **Belowground organic matter BG:** The below organic matter pool is estimated from the aboveground organic matter using a relationship between aboveground

and belowground organic matter, such as a root-to-shoot ratio. Similar to the constants used for the aboveground organic matter, the ration or allometry for estimating the belowground carbon density must be fixed during a baseline validation period.

4. **Lying deadwood organic matter (LDW):** Lying deadwood has been sampled with the line intersect method within the 1-ha permanent plots. Each piece of dead wood is assigned to one of three decay classes as (a) Sound, (b) Intermediate, or (c) Rotten, on the basis of a machete test. The estimated biomass for each dead wood piece is subject to density reduction factor. While the project proponent may use most applicable density reduction factor, the default density reduction factors are 1, 0.80, and 0.45 respectively for decay classes- sound, intermediate and rotten.
5. **Standing deadwood organic matter (SDW):** Standing dead trees must be measured using the same procedures used for measuring live trees with the addition of a decomposition class and the addition of an appropriate biomass reduction factor. Specifically, all the standing dead trees must be assigned with one of the two conditions (a) Dead trees which have lost only leaves and twigs, and (b) Dead trees which have lost leaves, twigs, and small branches (diameter < 10cm) and use an appropriate biomass reduction factor for each of the two conditions. The project proponent may use biomass reduction factors based on local or national data/study or use a default factor of 0.975 for trees in condition (a) and 0.80 for trees in condition (b). If the tree has lost all the branches, such a tree must be considered a Dead Tree Stump.
6. **Dead tree stump organic matter (DTS):** If the stump height is greater than the mid-point diameter of a stump or dead tree without branches, then the biomass must be estimated using the method found in Ormerod (1973). First, the volume of the dead tree stump must be estimated and then the wood density to estimate the biomass in DTS multiplies the volume.
7. **Soil organic matter (SOM):** Soil organic carbon pool must be estimated using soil samples taken at different soil horizons. The depth to which the soil samples are taken and analyzed must be at least 30 cm as per the recommendation of the IPCC GPG-LULUCF (2003). In these samples, depth, bulk density and concentration of organic dry matter must be recorded. For the BioREDD project, the soil carbon was not measured directly. However, we used the guidelines provided by the CDM AR tool 6.0 (Procedure to determine when accounting of the soil organic carbon pool may be conservatively neglected in CDM A/R project activities, Version 1.). We used a combination of soil maps for the region and the carbon numbers for up to 1.0 m depth to aggregate for the BioREDD regions and the LULC classes.

4. Carbon Estimation Methodology

The methodology to estimate carbon pools is based on three steps:

1. Ground estimation of carbon pools: We developed a series of field plots as described in earlier reports to sample the forest carbon pools in BioREDD

regions. The field survey and data collection occurred in summer of 2013 and ended in early 2014. The field plots included permanent (1-ha) and temporary plots (0.25 ha) over 16 study regions covering a variety of forest types including intact and degraded forests. The measurements included tree diameter for all trees > 10 cm. The 10 cm threshold was selected to meet the requirement of the VCS REDD methodological and IPCC guidelines. The measurements were converted to forest above ground biomass using a combination of existing allometric equations. However, we found large differences between the allometric equations, particularly between wet and moist forests from Chave et al. 2005. The Choco region has large variations of rainfall and species composition different from the central Amazonian trees where most of the harvested trees in Chave et al. (2005) equation are based on. Ground measurements also included the dead trees both the standing and lying to provide the carbon in standing and lying organic matter.

2. The BioREDD team developed a local allometric equation to convert the tree structure measurements in the field to biomass. The allometric models were developed based on a set of harvested trees. To develop the project based allometric model for biomass and carbon content measurements were performed by CONIF at four sites, two sites were in the Northern Pacific region near the Mutatá and Rio Pepe Indigenous Community Councils/ The other two sites were in the Southern Pacific region where fieldwork was conducted in late 2010 and early 2011 by CONIF and members of the Community Council in Bajo Mira and Frontera and Concosta (Saldarriaga, et al., 2011). All these four sites are within the BioREDD region with the aim of establishing REDD + projects in the future. The field work for the allometry model lasted four months, ~75 days of fieldwork and ~ 45 days of laboratory work. The main objectives of the study were:
    1. Adjust existing allometric functions for upland forests, including a greater number of species and individuals distributed in diameter classes from 10 cm with special emphasis in the higher classes (D> 70 cm).
    2. Develop models to estimate the biomass of secondary forests.
    3. Develop models to estimate the biomass of some species of palms.

    The selection of sites were based on several criteria such as community interest, state forest and diversity, coverage and scientific interest, safety in the work area, operating costs, logistics and transport. Working with communities was instrumental in achieving the objectives. We harvested 296 trees ≥ 5 cm diameter at four sites, two in the North Pacific and two in the South Pacific, including 240 from the mature forest trees, 56 trees of secondary forest and 97 palms. In turn, of the 240 individuals in the mature forest, 160 are from the terra firme forests in middle and low hilly regions (Colinas), 46 from the inundated forests near the coastal plain (Guandal), and 34 tree from the mangrove forests (Manglar).
3. Estimation of carbon pools in BioREDD regions: To extrapolate the ground measurements to the entire BioREDD regions, we made use of the estimates of aboveground biomass from lidar data randomly sampled in forest strata and LULC classes. From ground measurements, we developed carbon pools and ratios of the carbon pools to aboveground carbon density and used the aboveground carbon density derived from lidar and LULC map to extrapolate the

estimates over larger regions. The estimates also included error propagation approaches to derive the uncertainty of carbon pool estimates at LULC units within the BioREDD project areas.

4. The statistical approach included estimates of mean and variance of carbon pools from the plot data and extrapolating the mean and variance to the entire BioREDD regions. The methodology to extrapolate the estimates to the BioREDD region is described in section 11 below.

4. Aboveground Organic Matter in Trees (AGT):

For AGB estimations of sample plots, we used the allometric model developed for the study region by the BioREDD team. First we used the Chave et al. 2005 model for moist forests to estimate the biomass for each plots. However, the BioREDD project provided funding to develop local allometric equations for the trees of the Pacific coastal forests. The models developed for the region included three types of forests in the regions: Terra firme (Colinas), Inundated forests (Guandal), and mangrove forests (Manglar). Trees were harvested in the region and combined by harvested trees from past research activities to develop the models. With the data collected in the four sites the allometric models presented here were developed. Six models were used to estimate the biomass of mature forests of coastal Colombia. Of the six models, three are to estimate the biomass of mature forests generally three to estimate biomass as forest type, guandal, mangroves and colinas. In addition, three models were developed to estimate the biomass of secondary forests. Trees of all diameter classes including individuals with larger diameters found in the study are also included. Finally, two models to estimate the biomass of palms were developed. The three groups of models, mature forest, secondary forest and palms, are solid from a statistical point of view. However, it is considered that the models found for mature forest can more accurately estimate the biomass of all forests including succession forests, because the database trees mature forest includes individuals of all size classes including large trees turn includes the database from secondary forests.

However, all the models presented are solid from the statistical point of view. However, they need to be validated to determine which of the models best measured biomass. For independent validation data, either collected by other researchers or from other studies and sites are required.

The models included uncertainty analysis and comparison with Chave et al. (2005) and (2014) allometric equations and differences were reported (see BioREDD project report BR-SUBK-FP-022). The equations are summarized below:

Colinas $\ln(AGB) = -2.130+2.015\times\ln(D)+0.724\times\ln(H)+1.002\times\ln(WD)$

Guandal $\ln(AGB) = -2.328+1.833\times\ln(D)+0.724\times\ln(H)+0.151\times\ln(WD)$

Manglar $\ln(AGB) = -2.818+2.185\times\ln(D)+0.724\times\ln(H)+0.650\times\ln(WD)$

For estimation of the biomass of palm trees in all types of forests, we used the allometric equation developed by Saldarriaga (2014).

$$\ln(AGB) = -0.173+0.700\times\ln(D^2\times H\times WD)$$

For biomass values estimated in individual permanent and satellite plots see table 6.3. For each plot, we also have an indentifier and discription by the field group that summarizes the type an condition of the forests such as degraded, secondary forests, Guandal, Colinas, Manglar, etc. Most plots fall in mixed forests, therefore the biomass values estimated from allometric models are applied on the tree level to provide estimates of the biomass at the plot level.

For trees smaller than the threshold of 10 cm, we used a model based on several plot data including data in Panama, Colombia consulated from literature (Chave et al., 2003; Sierra et al., 2007; Usuga et al., 2010). The following model was used to estimate the ratio (R_t) of AGB for trees > 1 cm to AGB for trees > 10 cm. Once the ratio was applied, the total biomass was caluclated by:

$$R_t = 1.483 AGB_{10cm}^{-0.0613} \qquad n = 65, \quad R^2 = 0.91$$

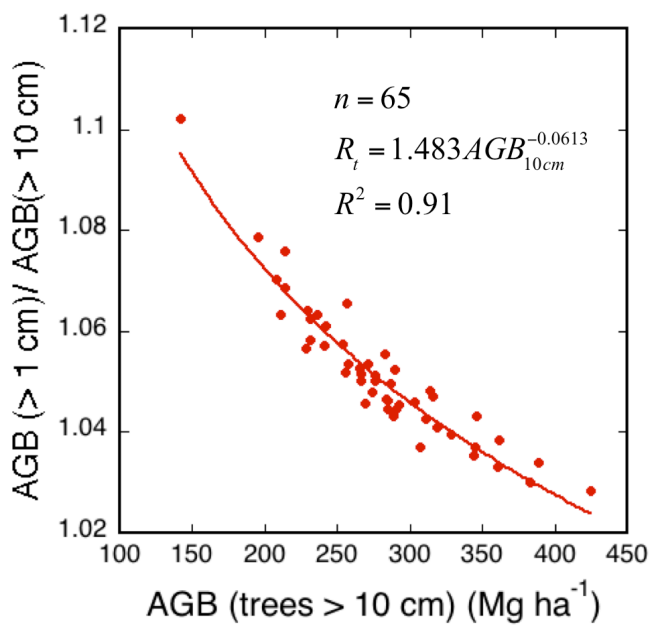

Fig. 4.1. The ratio of forest biomass with all trees > 1cm to biomass of trees above the threshold of 10 cm measured in the field. The ratio will correct the biomass from measurements to total biomass.

We used the carbon fraction value of $C_F = 0.485$ to convert the biomass to carbon numbers. This number is smaller than the conservative value of 50% suggested by the IPCC guideline, but is the average of values reported in the region and most Amazonian forests (Higuchi et al., 1994).

Table 4.1. Mean and standard deviation of forest biomass of 15 cluster plots within the BioREDD project areas.

Name of Cluster Plots	Number of WD samples	Average WD of Trees	Average WD of Trees and Palms	Average number of trees per ha	AGB (Mg ha^{-1})
Acapa	30	0.658	0.630	357	157.9 ± 50.6
Bahia_Malaga	81	0.551	0.531	636	232.1 ± 65.9
Bajo_Calima_I	100	0.562	0.537	694	168.6 ± 56.6
Bajo_Calima_II	70	0.593	0.563	634	184.7 ± 37.4
Bajo_Mira	30	0.569	0.543	460	118.1 ± 24.6
Buenavista	73	0.675	0.657	505	318.2 ± 40.0
Canton_S_Pablo	38	0.601	0.588	569	228.4 ± 51.7
Chigorodo	98	0.507	0.505	485	275.0 ± 95.4
Chontadural	168	0.503	0.480	538	221.8 ± 29.6
Concosta	84	0.636	0.606	612	376.5± 472.0
Curvarado	73	0.533	0.522	442	355.4 ± 157.0
Pizarro	81	0.518	0.495	396	175.9 ± 51.6
Rio_Cajambre	31	0.494	0.457	1300	138.5 ± 39.0
Rio_Pepe_I	160	0.487	0.476	538	181.1 ± 31.8
Rio_Pepe_II	160	0.524	0.502	769	230.3 ± 60.6

5. Aboveground Non-tree Organic Matter (AGNT):

The mean carbon stocks in the non-tree aboveground biomass pool per unit area are usually estimated based on previously published or default data or field measurements. Non-tree woody aboveground biomass pool includes trees smaller than the minimum tree size measured in the tree biomass pool, lianas, all shrubs, and all other non-herbaceous live vegetation. 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. For AGNT, we only use the shrubs and refer to literature to get a simple ratio between the aboveground biomass of shrubs vs the aboveground biomass of trees in forests (Philips et al. 1998; 2009; Araujo et al., 1996).

We used data from several sources with collected shrubs and lianas to develop a relationship between the biomass of shrubs and the biomass of trees > 10 cm in the forests. These plots are mainly in Panama (BCI; Condit et al., 2000), Costa Rica (La Selva; Clark et al., 2000), and Peru (Manu National Park; Malhi et al. 2010). The model developed from the data sets provide approximate values as suggested by various literature based on ground data (Philips et al. 1998; Brown and Lugo, 1992). The relationship between the ratio of shrub aboveground biomass and forest biomass (trees > 10 cm) is:

$$R_s = 0.832 AGB_{10cm}^{-0.654} \qquad n = 31, \quad R^2 = 0.76 \qquad (5.1)$$

For conversion of shrub biomass to carbon, we used the carbon fraction value of C_F=0.47 as recommended by VCS methodology default value for non-tree carbon pool.

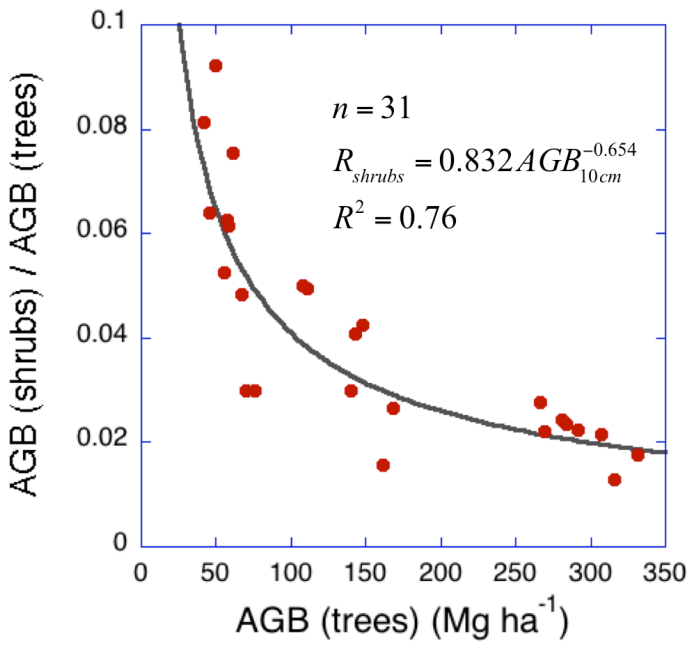

Fig. 5.1. Ratio of non-tree to aboveground live tree biomass in forests derived from field observations in tropical forests.

6. Belowground Organic Matter (BG):

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 to calculate belowground from aboveground biomass. It is not practical to measure below ground biomass in most tropical forests on a routine basis. It is also very difficult to develop an appropriate, country-specific allometric equation for root biomass. Instead below-ground biomass is estimated from a well-accepted ratio for moist tropical forests, developed by Mokany et al. (2006; also reported in the IPCC 2006 GL), which reliably predicts root biomass based on shoot biomass:

$$BGB = 0.235 * AGB \text{ if } AGB > 125 \text{ Mg ha}^{-1}$$

$$BGB = 0.205 * AGB \text{ if } AGB \leq 125 \text{ Mg ha}^{-1} \qquad (6.1)$$

Where:

BGB = below ground biomass
AGB = aboveground biomass

Most of our plots in terra firme forests had aboveground AGB > 125 Mg ha^{-1}. However, there were many degraded and secondary forests randomely selected in our plot systems

with slightly different biomass and probably different root-to-shoot ratios. We decided to use the data from Mokany et al. (2006) to develop a model that can be used on all forest types. This model was also used for estimating belowground biomass of tropical forests over three continents by Saatchi et al., (2011) . A synthesis of data from available literature, along with elimination of data collected using unclear or incorrect methods, provided an allometric model for estimating forest belowground biomass. We used this equation to estimate belowground biomass from aboveground biomass:

$$BGB = 0.489 * AGB^{0.89} \qquad (6.2)$$

where BGB is the belowground and AGB is the aboveground biomass in units of Mg ha^{-1} of dry weight. To develop an uncertainty in the above relationship, we used the measurements from Mokany et al. and examined the variations in the ratio of below:aboveground biomass or root:shoot biomass ratios with respect to vegetation types used in the study. By including sites in forest plantations and grasslands and tundra, the RMSE in predicting the belowground biomass was 9.46 Mg ha^{-1} and relative error of approximately 23.2% (Fig. 6.1). The application of the above model to estimate of BGB had standard error of 0.659 Mg ha^{-1}. For converting the belowground biomass to carbon(BG) , we used the carbon fraction value of 0.485 similar to aboveground carbon pool.

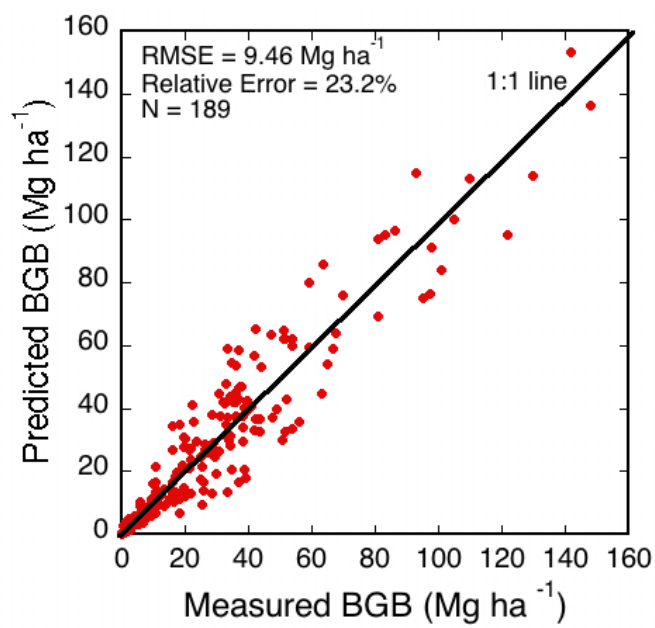

Fig. 6.1. Predicted versus measured BGB using an allometric equation and data from 189 field plots from Mokany et al. (*9*). The solid line shows the 1:1 with RMSE and the relative error. The data were obtained through personal communications with K. Mokany.

7. Lying and Standing Deadwood Organic Matter (LDW & SDW):

The methods for measuring the carbon stocks in dead wood, both lying and standing, are detailed in the standard operating procedures outlined in field measurement protocols

used by CONIF for the BioREDD project. The basic methods are as follows: (1) For standing dead wood, the volume of the main stem is estimated from measures of base diameter and height, This is then multiplied by the density of the species (if known or by the average density of 0.65). (2) For lying dead wood, measurements are taken to estimate the volume and its density class (sound, intermediate, and rotten) according to the methodology. Multiple samples of the three classes of dead wood are then collected to determine their average wood density (t m^{-3}) according to the methodology. The volume by density class times the dead wood density results in an estimate of the carbon stock in lying dead wood.
The final number of samples of dead wood will be a minimum of 30 samples per each BioREDD project area. These samples are collected within the 1-ha permanent plots and are used to estimate the mean and variance or standard error of deadwood biomass for each plots. To calculate the amount of dry mass contained in the coarse debris (DBH ≥ 10 cm) in permanent plots of 1-ha, the length and diameter at the ends of all fallen and standing tree logs were measured following the RAINFOR protocols. We used 462 points with samples of deadwood in all 15 1-ha permanent plots to calculate the biomass density (g cm^{-3}).

All individual and samples,except those of Chigorodó and Buenavista plots, were used to assign a decomposition class as follows: 1) Solid wood freshly fallen bark intact or starting their fall, occasionally occur fine branches still attached. 2) not solid wood, in poorer conditions than before, but still have trouble pushing a nail or knife hand. 3) decomposed, soft wood, which collapses easily to hit or stand with your feet.
The calculation of the dry mass of each log, obtained by multiplying the volume (m^3) by the density of each debris timber (WD) estimated from samples in the field. To obtain the volume of each log, we used the Smalian equation for volume of a tappered tree log:

$$vol = \frac{\pi L}{8}(d_1^2 + d_2^2) \qquad (7.1)$$

Where L is the length of the log and d_1 and d_2 are the diameter of a tappered log at two points.
To estimate the WD, a regression model between the class assigned to each log decomposition (1, 2 or 3) and laboratory WD calculated for the collected logs is generated (see BioREDD report for ground measurements). We found significant differences in mean WD for each decomposition class. Instead of using the density reduction factors for each decaying or decomposition classes, we directly estimate the wood density values to estimate the biomass. The mean values obtained in the laboratory provided a simple regression model fitting between the mean WD of 0.564 (g cm^{-3}) for the decomposition class 1, 0.411 (g cm^{-3}) for class 2, and 0.258 (g cm^{-3}) for class 3.
Having the volume of the logs in each sample plot and the wood density, we were able to estimate the dry biomass in (Mg ha^{-1}) of the standing, lying, and total deadwood for each cluster plots in the BioREDD project areas.
We then use the mean values and either develop a relationship between deadwood biomass and live wood biomass at the plot level or use a ratio to convert the aboveground live tree biomass to deadwood biomass in both standing and lying deadwood. In developing the model or the ratio for estimating deadwood biomass from the aboveground live biomass, we also explored the use of ancillary parameter such as the degree of fragmention or canopy cover derived from lidar data over each plot to improve

the estimation of deadwood. Introudcing ancillary parameter such as fraction cover is based on the fact that the biomass of deadwood increases in degraded and secondary forests compared to intact old growth forests. The use of ancilary data improved the estimate to some extent

$$AGB_{SDW} = \frac{0.000484}{f} AGB_{10cm}^{1.614}$$

$$AGB_{LDW} = \frac{0.0353}{f} AGB_{10cm}^{1.093} \qquad (7.2)$$

$$AGB_{Total} = \frac{0.0424}{f} AGB_{10cm}^{1.106}$$

where f is the fraction cover of trees within each plot. The fraction cover is estimated from the lidar data by separating the gaps from tree crown cover within each permanent plot. The same method can be used during the ground survey of deadwood by fisheye photography or other forestry techniques. To convert the biomass to carbon, we used the default value of 0.485 as in live tree components to estimate the carbon pool values.

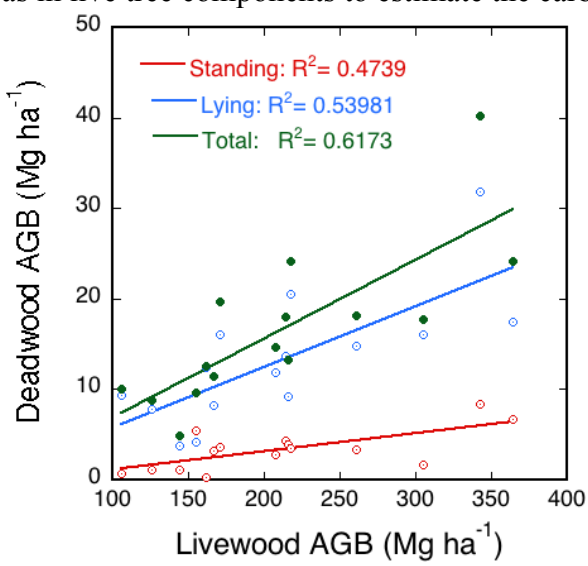

Fig. 7.1. Relationship between aboveground biomass of trees > 10 cm diameter measured in the plot and the deadwood biomass in standing, lying, and total. The deadwood biomass numbers have been improved by correcting them with the fraction of cover as shown in the above relations.

Table 7.1. Summary of the data used to estimate the total dry mass (Mg ha^{-1}) of deadwood in each of the 15 cluster sample plots and partitioned in lying and standing components in forests of BioREDD region.

Name of	Number of	Average	Number of	Biomass of	Biomass of	Total

Cluster Plots	Laboratory samples	Wood Density	sample plots	standing deadwood ($Mgha^{-1}$)	lying deadwood ($Mgha^{-1}$)	Biomass of deadwood ($Mgha^{-1}$)
Acapa	37	0.520	112	1.2	3.8	5.0
Bahia_Malaga	30	0.486	407	4.8	27.8	32.6
Bajo_Calima_I	30	0.544	173	6.1	4.7	10.8
Bajo_Calima_II	30	0.435	339	5.5	24.8	30.3
Bajo_Mira	30	0.249	386	1.2	15.9	17.1
Buenavista	30	0.498	170	1.8	16.5	18.3
Canton_S_Pablo	35	0.492	78	5.4	16.9	22.3
Chigorodo	30	0.321	397	4.0	17.4	21.4
Chontadural	30	0.233	53	3.2	13.7	16.8
Concosta	30	0.409	144	7.6	19.6	27.2
Curvarado	30	0.333	364	10.3	39.3	49.6
Pizarro	30	0.518	289	0.3	15.9	16.2
Rio_Cajambre	30	0.381	217	1.6	11.6	13.1
Rio_Pepe_I	30	0.401	460	3.6	9.2	12.8
Rio_Pepe_II	30	0.308	337	4.6	10.9	15.6

8. Litter or Dead Tree Stump Organic Matter (DTS):

For estimating carbon stock in litter, four litter samples are collected from each sample plot, using a sampling frame, which is placed, in four randomly selected positions within the plot. The four samples are well mixed into one composite sample and its wet weight is taken. A sub-sample taken from the composite sample is weighed, oven dried, and weighed again to determine its dry weight. The dry-to-wet weight ratio of the sub-sample is calculated and used for estimating the dry weight of the composite litter sample.

If PPs do not wish to make sampling based measurements for estimation of C stock in litter, they may use the default-factor based method described in this section. The default-factor based method is applicable only if litter remains in situ and is not removed from the project boundary through any type of anthropogenic activities.

Value of the conservative default factor expressing carbon stock in litter as a percentage of carbon stock in tree biomass is selected according to the guidance provided in the relevant table in Section 8 unless transparent and verifiable information can be provided to justify a different value.

Table 8.1. Default values of litter carbon stocks in terms of the aboveground live tree carbon stocks.

Biome	Elevation	Rainfall	Default Factor
Tropical	<2000 m	< 1000 mm/yr	4%
Tropical	<2000 m	1000-1600 mm/yr	1%
Tropical	<2000 m	> 1600 mm/yr	1%
Tropical	>2000 m	All	1%

For the BioREDD project, we have also consulted the literature for estimates of litter and tree stumps in forest floor in Colombia. Data from sample plots in Colombia (Sierra et al. 2007) collected in six 1 m^2 (1 m x 1 m) subplots within permanent plots were used to

also estimate the ratio of aboveground biomass of combined fine litter and herbaceous and non-woody material to the total live tree biomass in the plot. In these plots all herbaceous and non-woody vegetation < 1 cm in D and all standing fine litter. Herbaceous vegetation and fine litter were completely harvested from these subplots and all material transported to the laboratory for subsequent dry weight determination. The methodology developed by Sierra et al. (2007) is similar to the IPCC guidelines for estimating carbon pool in litter.

Old Growth: $AGB_{litter} = 0.01538 * AGB_{10\ cm}$, SE=1.337 Mg ha^{-1}

Degraded/Secondary Forest: $AGB_{litter} = 0.09438 * AGB_{10\ cm}$, SE=0.3417 Mg ha^{-1} (8.1)

We found the above relations more relevant to the BioREDD study region. All data are from Porce in the provice of Antioquia, Colombia adjacent to northern Choco region of Colombia.

9. Soil Organic Matter (SOM):

Deforestation and conversion of forest to croplands and grasslands can change the soil carbon to varying degrees depending on the post-deforestation practices with carbon inputs and outputs in the soil system. The main management practices that affect soil C stocks in croplands are the type of residue management, tillage management, fertilizer management (both mineral fertilizers and organic amendments), choice of crop and intensity of cropping management (e.g., continuous cropping versus cropping rotations with periods of bare fallow), irrigation management, and mixed systems with cropping and pasture or hay in rotating sequences. In addition, drainage and cultivation of organic soils reduces soil C stocks (IPCC 2006 GL, Vol. 4, Ch. 5). Therefore, it is necessary to estimate the soil carbon through inventory techniques and estimate the changes of soil carbon. Soil samples must collected in each project areas as described in the IPCC guidelines. Soil carbon emissions will be estimated according to the IPCC 2006 GL method for conversion of forests to croplands (and assumed can be used for all deforestation activities that disturb the soil) as follows:

$$\Delta C = (SOC_0 - SOC_D)/D$$

$$SOC = SOC_{REF} * F_{LU} * F_{MG} * F_I \quad (9.1)$$

Where:

SOC_0 and SOC_D = initial soil organic carbon and soil organic carbon at the default time to reach equilibrium (at time D); t C ha^{-1} to 30 cm depth

D = Time dependence of stock change factors, which is the default time period for transition to a new equilibrium SOC value; year (20 years)

SOC_{REF} = reference carbon stock; MgC ha^{-1} to 30 cm (from the field soil sampling work; see below)
F_{LU} = stock change factor for land-use systems or sub-system for a particular land-use, dimensionless
F_{MG} = stock change factor for management regime, dimensionless
F_I = stock change factor for input of organic matter, dimensionless

The values of F_{LU}, F_{MG}, and F_I for different activities in the BioREDD region. Here, we provide estimates of reference soil carbon SOC_{REF} up to 30 cm depth for the project region by using existing data and maps available for the coastal of Colombia. There were no direct sampling of soil carbon pools during the BioREDD project. Therefore, we followed a default methodology to estimate soil carbon pools in LULC classes using a combination of data published in the literature and soil maps with carbon values at 30 cm horizon.

1. Ex ante estimation of pre-deforestation stocks of soil organic carbon

To estimate the carbon stock in soil organic carbon per unit area for LULC classes at time t, we used data from literature for tropical moist forests and secondary and degraded forests of Colombia (Sierra et al., 2007). Soil sample data collected in this study showed that the organic carbon concentrations in soils in the first 30 cm were 29.8 ± 0.73 mg g^{-1} for primary forests and 23.4 ± 0.6 mg g^{-1} for secondary forests. Evidence for a reduction of organic carbon concentrations in secondary forests was observed (**p** -value < 0.05 from a two-sample comparison) compared to primary forests. Using a correction factor for the differences in bulk density between forest age-classes, the estimated SOC to 30 cm depth was 96.60± 2.47 Mg ha^{-1} in primary forests and 72.18 ± 2.54 Mg ha^{-1} in secondary forests. These numbers allowed us to have a base value for calibration of the soil carbon values for the BioREDD region.

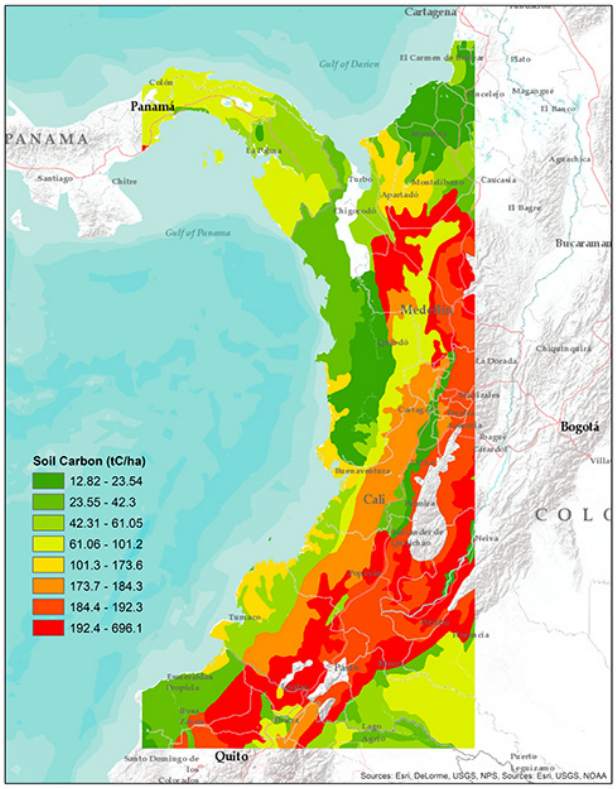

Fig. 9.1 Soil carbon map of the Pacific coastal region of Colombia derived from global Harmonized soil map (FAO).

We also used the harmonized soil carbon map produced by FAO (See Fig. 9.1). The Harmonized World Soil Database is a 30 arc-second raster database with over 15 000 different soil mapping units that combines existing regional and national updates of soil information worldwide (SOTER, ESD, Soil Map of China, WISE) with the information contained within the 1:5 000 000 scale FAO-UNESCO Soil Map of the World (FAO,

1971-1981). The soil map has a standardized structure with various attributions that allows for the linkage of the attribute data with the raster map to display or query the composition in terms of soil units and the characterization of selected soil parameters (organic Carbon, pH, water storage capacity, soil depth, cation exchange capacity of the soil and the clay fraction, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity, textural class and granulometry).

We intersected the soil map with the LULC map for the BioREDD region. The soil map is at 1 km spatial resolution and the LULC map at 30 m spatial resolution. We first calculated the number of 1-km pixels within each LULC class in each BioREDD project region and treated the soil map pixels as the sample value. Using the carbon content at the 30 cm horizon, we estimated the mean and the variance of the carbon in organic soil layer using the following steps:

1. Compute the soil carbon content from the map for the primary and secondary forests in the Ponce region and estimate the calibration values for the harmonized soil map by comparing the two estimates. We found that an average calibration value of 0.93 for the primary forest and 0.89 for the secondary or degraded forest (both are the same class in our map). We used these factors to correct all forest and degraded/secondary forest classes in LULC. For other land cover classes, we used the forest calibration class of 0.93 for correction.
2. We counted all 1-km pixels in the land cover classes and estimated the mean carbon density and variance for each stratum or LULC class using:

$$\mu_y = \sum_{j=1}^{m} w_j \mu_{yj}$$

$$\mathrm{var}(\mu_y) = \sum_{j=1}^{m} w_j^2 \,\mathrm{var}(\mu_{yj}) = \sum_{j=1}^{m} w_j^2 \frac{s_j^2}{n_j} - \sum_{j=1}^{m} w_j \frac{s_j^2}{N}$$

where

μ_y : mean carbon density in project area

μ_{yj} : mean carbon density in stratum j 9.2

m:number of stratum in project area

w_j: proportion area of stratum j

s_j^2 : sample variance within stratum j with

n_j: number of sample units in stratum j

3. After estimating carbon in all LULC classes, we adjust the numbers for deforested lands to reflect the impact of activities in croplands and grasslands in soil organic carbon content for the baseline estimates.

2.Ex ante adjustment of post-deforestation stocks of soil organic carbon:

Post-deforestation soil carbon stocks are assumed to be the long-term average stocks on

the land following deforestation. To estimate this long term average post-deforestation stock of soil organic carbon, the mean soil stock estimated in Part 1 at t=0 is multiplied by the stock change factors, equal to the carbon stock in the altered condition as a proportion of the reference carbon stock as defined in IPCC 2006GL2. This method assumes that changes will take place over 20 years and is assumed to equate to the long-term average stocks. After estimating carbon in all LULC classes, we adjust the numbers for deforested lands to reflect the impact of activities in croplands and grasslands in soil organic carbon content for the baseline estimates. We consulted several papers in the lierature with large meta data analysis for adjustment of the carbon stocks in grasslands and croplands (Guo and Gifford, 2002; Don et al., 2011). Overall, the Primary forest to grassland (-12.1%) , Primary forest to cropland (-25.2%) , Primary forest to perennial crops (-30.3%), and Primary forest to secondary forest (-8.6%).

10. Estimation of Mean and Standard Error of Carbon Pools

Estimating carbon pools in all LULC classes for BioREDD project areas are based on the aboveground live carbon pool derived from 83,000 lidar data interesected by land use and land cover classes as described in report 8&9. We estimate the belowground, standing and lying deadwood, the non-tree carbon pool, litter using models and factors developed above on each ha of lidar derived aboveground pool. The approach is summarized as follows:

$$AGT = CF_{AG} \times (1.483 AGB_{10cm}^{-0.0613})$$

$$AGNT = CF_{AGNT} \times (0.832 AGB_{10cm}^{0.346})$$

$$BG = CF_{BG} \times (0.489 AGB^{0.89})$$

$$LDW = CF_{LDW} \times (\frac{0.0353}{f} AGB_{10cm}^{1.093})$$

$$SDW = CF_{SDW} \times (\frac{0.000484}{f} AGB_{10cm}^{1.614})$$

$DTS = CF_{DTS} \times (0.01538 AGB_{10cm})$: Intact Forest

$DTS = CF_{DTS} \times (0.09438 AGB_{10cm})$: Degraded & Seconadry Forest

where

$$CF_{AG} = 0.485, CF_{BG} = 0.485, CF_{AGNT} = 0.47, CF_{LDW} = 0.485, CF_{SDW} = 0.485, CF_{DTS} = 0.485$$

10.1

In above equations, AGB_{10cm} is the estimated aboveground biomass from lidar data. For each land cover type, the mean and variance will follow equations (9.2). We have also adjusted the variance and the standard error taking into account the clustering nature of the lidar data. As lidar data have been collected along a transect, the biomass estimation errors are spatially correlated and this spatial correlation in turn increases the error associated with large area variance estimation.

$$E = \frac{z_v \sigma_L}{\sqrt{n}}$$

$$\sigma_L = \left(\sum_i \sigma_{ui}^2 + 2 \sum_i \sum_j \rho(d) \sigma_{ui} \sigma_{uj} \right)^{1/2}$$

$$\rho(d) = \exp(-\frac{d}{cr}), \qquad 10.2$$

E: error at LULC class

r: range from semivariogram,

c: coefficient from Moran-I

σ_u^2 : variance associated with lidar model error for each 1-ha pixel i

second term represents the variance associated with the spatial correlation

In above relationship E is the standard error associated with the a small number to allow accurate estimate of biomass from lidar relative to ground observations. For 95% confidence interval, the z_v=1.96. Without spatial correlation, $\sigma_L = \sigma_u$ and since n is a large number (number of pixels in each LULC class), the standard error would become negligible. However, by including the spatial correlation, the standard error appraoches a more realistic value.

Using, the above equations, we estimate the carbon pools in all LULC classes in the BioREDD project areas as summarized in Table 10.1.

Table 10.1. Estimates of carbon pool and standard errors associated with LULC in BioREDD project areas. The LULC classes are: 1. Intact tropical forest terra firme, 2. Degraded or secondary forests. 3. Grasslands, 4. Croplands, 5. Wetlands, 6. Settlements, and 7. Other lands.

Project Areas	LC	AGT	AGT-SE	BG	BG-SE	AGNT	AGNT-SE	LDW	LDW-SE	SDW	SDW-SE	DTS	DTS-SE	SOC	SOC-SE
BMBC	1	137.85	3.05	38.89	2.24	3.24	0.34	12.79	0.54	3.66	0.29	2.06	0.45	76.86	5.38
	2	53.98	3.71	16.88	2.76	2.67	0.42	17.8	1.11	6.26	0.73	2.9	0.94	72.87	3.9
	3	15.78	4.47	8.75	3.43	1.67	0.5	11.16	1.34	1.33	0.79	1.8	1.12	59.55	5.19
	4	20.51	2.48	10.16	1.92	1.67	0.28	11.1	0.74	1.02	0.4	1.78	0.62	64.64	5.41
	5	15.96	4.33	5.71	3.36	1.98	0.49	0	0	0	0	0	0	47.29	4.37
	6	6.56	0.91	2.59	0.77	0.8	0.1	0	0	0	0	0	0	54.3	4.09
	7	17.96	1.31	6.34	1.16	0.54	0.15	0	0	0	0	0	0	17.82	1.56
CDD	1	161.02	3.46	27.84	5.02	2.84	0.76	17.35	1.21	3.3	0.64	1.81	1	39.23	5.38
	2	36.98	2.41	12.06	3.94	1.11	0.57	7.4	1.52	2.14	0.89	1.19	1.27	38.88	3.9
	3	16.97	2.64	6.03	2.17	0.96	0.3	6.39	0.79	1.42	0.35	1.01	0.64	40.11	5.19
	4	8.5	4.46	3.26	3.4	1.46	0.5	9.7	1.34	1.77	0.82	1.56	1.12	42.64	5.41
	5	10.82	1.89	4.04	1.59	0.32	0.21	0	0	0	0	0	0	42.32	4.37
	6	0.29	0.09	1.63	0.46	0.01	0	0	0	0	0	0	0	39.16	4.09
	7	34.03	3.48	11.2	2.78	1.02	0.39	0	0	0	0	0	0	43.44	1.56
SUPP	1	141.4	4.4	40	3.27	3.16	0.49	16.64	0.78	3.62	0.39	2.01	0.64	44.96	5.38
	2	68.05	4.7	20.9	3.6	2.03	0.53	14.44	1.41	4.38	0.83	2.19	1.18	57.47	3.9
	3	10.41	3.88	3.9	3.09	0.76	0.44	5.08	1.16	1.26	0.6	0.81	0.96	59.01	5.19
	4	5.85	3.67	2.34	2.89	1.53	0.41	10.17	1.1	1.83	0.57	1.63	0.91	49.48	5.41
	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6	8.31	0.66	3.19	0.63	0.25	0.07	0	0	0	0	0	0	52.96	4.09
	7	26.7	4.39	9.02	3.4	1.4	0.49	0	0	0	0	0	0	37.14	1.56
BMF_ACAPA	1	153.5	9.36	43.02	4.4	1.95	0.65	16.02	1.03	1.95	0.49	1.23	0.85	72.29	5.38
	2	78.3	4.3	23.62	2.62	1.22	0.37	18.35	0.98	2.06	0.48	1.3	0.81	77.24	3.9
	3	12.94	3.1	4.73	2.54	0.84	0.35	5.59	0.93	1.27	0.41	0.89	0.76	81.96	5.19
	4	17.65	2.66	6.24	2.14	1.13	0.3	7.53	0.8	1.76	0.37	1.2	0.65	78.14	5.41
	5	15.3	2.14	5.5	1.8	0.46	0.24	0	0	0	0	0	0	47.29	4.37
	6	7.28	0.54	2.84	0.5	0.22	0.06	0	0	0	0	0	0	72.1	4.09
	7	22.66	1.96	7.8	1.68	0.68	0.22	0	0	0	0	0	0	85.86	1.56
CAJAMBRE	1	136.08	3.56	38.79	2.63	3.3	0.4	13.06	0.63	3.8	0.32	2.1	0.52	60.55	5.38
	2	69.33	4.6	21.09	3.47	2.83	0.52	18.87	1.38	6.97	0.86	3.09	1.16	57.67	3.9
	3	17.18	3.57	9.17	2.85	1.12	0.4	7.44	1.07	1.87	0.54	1.19	0.88	65.46	5.19
	4	28.53	2.92	12.51	2.23	1.76	0.33	11.71	0.88	3.31	0.51	1.88	0.73	61.62	5.41
	5	24.09	3.53	8.23	2.67	2.22	0.4	0	0	0	0	0	0	47.29	4.37
	6	5.75	0.7	2.3	0.56	0.17	0.07	0	0	0	0	0	0	44.4	4.09
	7	5.8	0.12	2.32	0.11	0.17	0.01	0	0	0	0	0	0	17.81	1.56
CONCOSTA	1	148.83	4.3	41.77	3.19	3.18	0.48	16.82	0.76	3.65	0.38	2.02	0.63	54.53	5.38
	2	81.77	4.34	24.43	3.31	2.16	0.49	24.34	1.3	4.72	0.77	2.34	1.09	61.74	3.9
	3	15.76	3.18	8.74	2.62	0.77	0.36	5.15	0.96	1.17	0.42	0.82	0.78	76.72	5.19
	4	22.16	3.14	10.65	2.5	1.41	0.35	9.43	0.94	2.48	0.47	1.51	0.78	52.12	5.41
	5	23.51	2.84	8.06	2.37	0.71	0.32	0	0	0	0	0	0	61.48	4.37
	6	3.27	0.32	1.39	0.34	0.1	0.04	0	0	0	0	0	0	63.11	4.09
	7	16.48	1.71	5.87	1.48	0.49	0.19	0	0	0	0	0	0	67.55	1.56
MUTATA	1	129.27	4.5	36.72	3.26	3.58	0.51	14.15	0.8	4.35	0.44	2.28	0.67	61.34	5.38
	2	71.79	5.59	21.76	4.15	3.05	0.63	20.36	1.68	7.97	1.13	3.35	1.42	99.52	3.9
	3	16.35	4.52	8.92	3.4	1.69	0.51	11.27	1.36	3.37	0.86	1.82	1.14	60.97	5.19
	4	29.79	4.65	12.87	3.49	2.24	0.52	14.96	1.4	5	0.9	2.43	1.18	73.18	5.41
	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6	14.38	4.45	8.32	3.67	1.03	0.5	0	0	0	0	0	0	45.04	4.09
	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RIO_PEPE_ACABA	1	130.79	4.09	37.11	3.02	2.87	0.46	11.36	0.73	3.12	0.37	1.82	0.6	20.72	5.38
	2	52.51	3.9	16.47	2.9	2.63	0.44	17.5	1.17	6.13	0.76	2.86	0.99	18.33	3.9
	3	15.88	3.79	8.78	2.9	1.53	0.43	10.18	1.14	2.83	0.65	1.63	0.95	19.3	5.19
	4	27.7	3.11	12.27	2.37	1.73	0.35	11.54	0.93	3.26	0.55	1.85	0.78	19.39	5.41
	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6	16.96	0.91	12.05	0.74	1.11	0.1	0	0	0	0	0	0	16.02	4.09
	7	32.55	3.56	10.76	2.7	1.58	0.4	0	0	0	0	0	0	15.72	1.56

11. References

Araujo T.M., Higuchi N., Carvalho Jr. J.A. Comparação de métodos para determinar biomassa na região amazônica (1996) Anais da Academia Brasileira de Ciencias, 68 (SUPPL. 1) , pp. 39-40.

Chave, J., Condit, R., Lao, S., Caspersen, J. P., Foster, R. B., & Hubbell, S. P. (2003). Spatial and temporal variation of biomass in a tropical forest: results from a large census plot in Panama. *Journal of ecology*, *91*(2), 240-252.

Chave, J., Condit, R., Aguilar, S., Hernandez, A., Lao, S., & Perez, R. (2004). Error propagation and scaling for tropical forest biomass estimates. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, *359*(1443), 409-420.

Chave, J., Andalo, C., Brown, S., Cairns, M. A., Chambers, J. Q., Eamus, D., ... & Yamakura, T. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia*, *145*(1), 87-99.

Chave, J., Réjou Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M. S., Delitti, W. B., & Vieilledent, G. (2014). Improved allometric models to estimate the aboveground biomass of tropical trees. *Global change biology*.

Don, A., Schumacher, J., & Freibauer, A. (2011). Impact of tropical land□use change on soil organic carbon stocks–a meta□analysis. *Global Change Biology*, *17*(4), 1658-1670.

Guo, L. B., & Gifford, R. M. (2002). Soil carbon stocks and land use change: a meta analysis. *Global change biology*, *8*(4), 345-360.

Hiederer, H. and M. Köchy 2012. Global Soil Organic Carbon Estimates and the Harmonized World Soil Database. EUR Scientific and Technical Research series – ISSN 1831-9424 (online), ISSN 1018-5593 (print), ISBN 978-92-79-23108-7, doi:10.2788/13267.

Higuchi, N., Carvalho Jr., J.A., 1994. Fitomassa e Conteu«do de Carbono de Espe«cies Arbo« reas da Amazoö nia. Semina& rio Emissa**8**o x Sequ(estro de CO2 uma nova oportunidade de nego& cios para o Brasil, Companhia Vale do Rio Doce, Rio de Janeiro, pp. 125‹153.

Ladd, B., Laffan, S. W., Amelung, W., Peri, P. L., Silva, L. C., Gervassi, P., ... & Sheil, D. (2013). Estimates of soil carbon concentration in tropical and temperate forest and woodland from available GIS data on three continents. *Global ecology and biogeography*, *22*(4), 461-469.

Mokany, K., Raison, R., & Prokushkin, A. S. (2006). Critical analysis of root: shoot ratios in terrestrial biomes. *Global Change Biology*, *12*(1), 84-96.

Panagos P., Van Liedekerke M., Jones A., Montanarella L. European Soil Data Centre: Response to European policy support and public data requirements. (2012) Land Use

Policy, 29 (2), pp. 329-338. doi:10.1016/j.landusepol.2011.07.003.

Phillips, O. L., Malhi, Y., Higuchi, N., Laurance, W. F., Núnez, P. V., Vásquez, R. M., ... & Grace, J. (1998). Changes in the carbon balance of tropical forests: evidence from long-term plots. *Science*, *282*(5388), 439-442.

Phillips, O. L., Aragão, L. E., Lewis, S. L., Fisher, J. B., Lloyd, J., López-González, G., ... & Andrade, A. (2009). Drought sensitivity of the Amazon rainforest. *Science*, *323*(5919), 1344-1347.

Saatchi, S. S., Harris, N. L., Brown, S., Lefsky, M., Mitchard, E. T., Salas, W., ... & Morel, A. (2011). Benchmark map of forest carbon stocks in tropical regions across three continents. *Proceedings of the National Academy of Sciences*, *108*(24), 9899-9904.

Saldarriaga, J. C., Hoyos, D. Á., & Correa, M. A. (2011). Avaliação de processos biológicos unitários na remoção simultânea de nutrientes para minimizar a eutrofização. *Revista EIA*, (15), 129-140.

Sierra, C. A., del Valle, J. I., Orrego, S. A., Moreno, F. H., Harmon, M. E., Zapata, M., ... & Benjumea, J. F. (2007). Total carbon stocks in a tropical forest landscape of the Porce region, Colombia. *Forest Ecology and Management*, *243*(2), 299-309.

Weisbin, C. R., Lincoln, W., & Saatchi, S. (2013). A Systems Engineering Approach to Estimating Uncertainty in Above□Ground Biomass (AGB) Derived from Remote□ Sensing Data. *Systems Engineering*.