BIOREDD+ Program

DELIVERABLE 14: MRV SYSTEM AND CARBON CALCULATOR

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About this Document

This document has been developed for USAID´s BIOREDD+ Program to provide the climate monitoring activities during the BIOREDD+ crediting period. The document summarizes the measurements required for updating and revising the baseline emission factors, the remote sensing approach for monitoring LULC for estimating the emissions and removals during the crediting period and before any verification events.

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List of Acronyms

AFOLU	Agriculture, Forestry and Other Land use
AGB	Above Ground Biomass
ALOS	Advanced Land Observing Satellite
BGB	Below Ground Biomass
BMyF	Bajo Mira y Frontera
CCBA	Carbon Communities and Biodiversity Alliance
CELI	Consolidation and Enhanced Livelihoods
CONIF	Corporación Nacional de Investigación y Fomento Forestal, National Corporation on Forestry Promotion and Research
CSR	Corporate Social Responsibility
DCA	Development Credit Authority
DEM	Digital elevation Model
ESPA	Environmental Service Purchase Agreement
FAAN	Fondo para la Acción Ambiental y la Niñez
FPIC	Free Prior Informed Consent
GOC	Colombian Government
HRP	Human Rights Program
IDEAM	Instituto de Hidrología Meteorología y Estudios Ambientales, Institute of Hydrology, Meteorology and Environmental Studies
INCODER	Instituto Colombiano de Desarrollo Rural
IRR	Internal Rate of Return
LIDAR	Laser Image Detention and Ranging
LOI	Letter of Intent
MIDAS	Más Inversión para el Desarrollo Sostenible
MODIS	Moderate-Resolution Imaging Spectroradiometer
MRV	Monitoring Registry and Verification
NASA	National Airspace Agency
NPC	Naidi Production Company
NPV	Net Present Value
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PD	Project Document
PES	Payment for Environmental Services
REDD	Emissions Reductions from avoided Deforestation and Degradation
SAR	Synthetic Aperture Radar
SMEs	Small and medium-sized enterprises
SPV	Special Purpose Vehicle
TA	Technical Assistance
TBD	To be determined
tCO2e	Ton of carbon dioxide equivalent
TGC	Terra Global Capital
USAID	United States Agency for International Development
US$	United States Dollar
VCS:	Verified Carbon Standard
VCU:	Verified Carbon Unit

Executive Summary

This document summarizes the standard operating procedures for the measurements and monitoring of carbon stocks and changes to quantify the climate benefits for the USAID BioREDD projects in the Pacific Coast of Colombia. Here, we outline the methodology for measurements to update the carbon emissions before the first verification and provide the monitoring approach, data sources, and organization for the entire crediting period. The project will monitor all required components according to the VM0006 methodology. In general, all components for calculating actual GHG benefits generated by the REDD+ project, or Net anthropogenic Emission Reductions (NERs) are included in the monitoring plan:

1. Monitoring of deforestation drivers, project activities and emission sources related to REDD+ project activities inside and outside of the Project Area.
2. Monitoring of degradation drivers, project activities and emission sources related to REDD+ project activities inside and outside of the Project Area.
3. Monitoring LULC class transitions in the Project Area, Leakage Area and Reference Region

A monitoring report is produced which contains all of the information above, and outlines the calculations for actual NERs generated. The tools in BioREDD MRV system will focus the measurements to update the emission factors for degraded forests and primary forests by collecting new lidar data over these areas. The monitoring plan will track down changes of forest to non-forest, non-forest to forest, forest degradation and forest recovery systematically by monitoring LULC transitions. The approach will also show how to integrate remote sensing data specific for the region (ie, Landsat, ALOS-PALSAR, Lidar, etc.) in monitoring tools along with repeated lidar flights for updates of baseline emission factors to calculate annual carbon change, within the required statistical error (10% at 95% confidence interval) over the project, reference, and leakage areas. All tools and measurements techniques and calculations are developed in accordance with VM0006 and VCS AFOLU requirements.
The BioREDD project will be using the Verified Carbon Standard VM0006 methodology for the quantification of carbon stocks and net emission reductions, as well as comprehensive analysis of satellite imagery performed by GeoEcoMap.

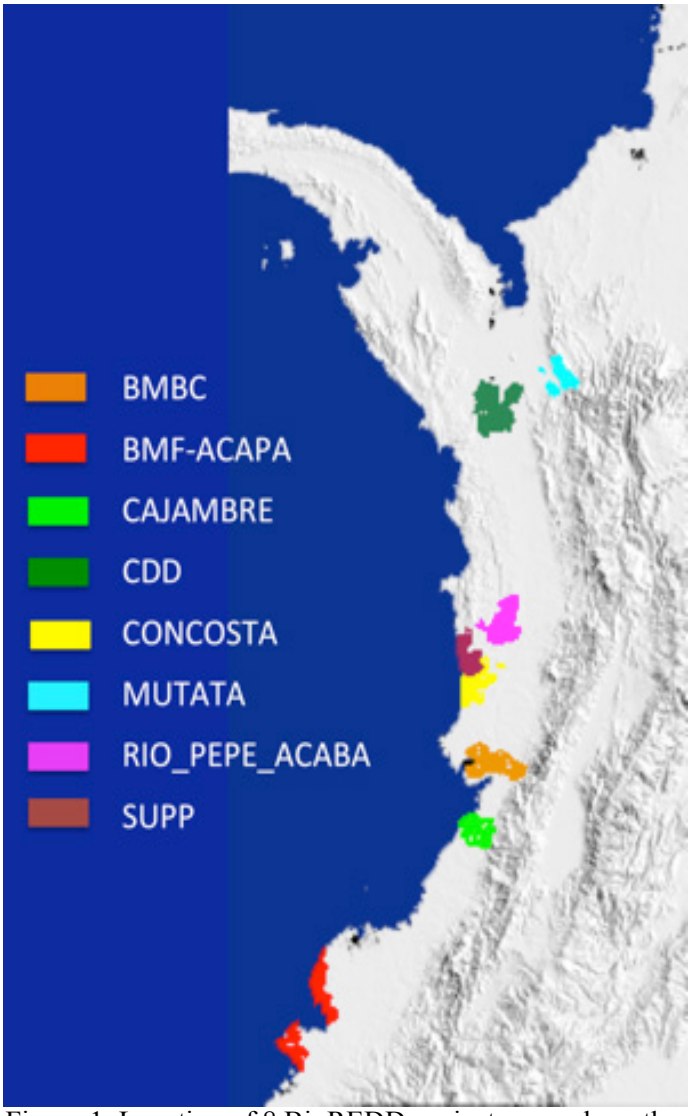

Figure 1. Location of 8 BioREDD project areas along the Pacific Coast of Colombia.

1 Introduction & Context

The BioREDD project started in 2012 as the flagship environmental program of the United States Agency for International Development (USAID) in Colombia. This US$ 27.9 million program is designed to strengthen Colombian capacity to mitigate and adapt to climate change, protect biodiversity and support the development of remote, impoverished communities. The development of REDD+ projects is a key element of the Program, which seeks to promote sustainable livelihoods compatible with forest conservation. BIOREDD+ is developing a portfolio of 8 REDD+ projects in the Colombian Pacific to be validated under the Climate, Community and Biodiversity Alliance (CCBA) and the Verified Carbon Standard (VCS). The projects are located in four geographic nodes covering over 700,000 hectares.

Number of BioREDD Projects

The BioREDD project selected eight areas along the Pacific coastal region of Colombia for developing REDD+ projects (Figure 1). These areas are distributed in different municipalities along the pacific coastal forests of Colombia, covering a variety of ecosystems, transitioning from coastal mangroves and wetlands to *paramos* and high mountain forests. This area forms part of the Chocó Biogeographic corridor, one of the 10 world´s mega-diverse hotspots that accounts for more than 40% of the total vertebrate population of Colombia. The REDD+ projects will be established in the territories of afrocolombian and indigenous communities along the coast where forests have been degraded and are under the threat of further degradation and deforestation for a variety of reasons. The main drivers of forest cover change have been identified as degradation from timber extraction for fuel and development needs, illegal logging, gold mining, and conversion of forests to agriculture and livestock. The projects are being developed jointly with local communities who have clear legal title to their land and have themselves agreed to REDD+ project development. They will be implementing REDD+ project activities with the expectation of generating revenues in exchange for their conservation efforts.

2 Measurement Methods

The monitoring plan will include collection of airborne lidar data before the first verification event to update the emission factors for degraded forests and primary forests. These are the only measurements to update the baseline emission factors before the first verification to reduce the uncertainty discounts required by VM0006. Following the VM0006 requirements (9.3.2 & 9.3.9), the emission factors will be updated before each baseline updates every 10 years. All calculations of emissions and removals during the crediting period will be based on monitoring LULC transitions and using the emission factors fixed between the two baseline updates except for the intact forests that may have undergone through selective and small scale degradation that are not detected by remote sensing LULC monitoring techniques. In this case, additional measures of conservativeness will be applied for updating the emission factors for intact or primary forests before the next lidar flights. A summary of measurement methods and standard operating procedures for lidar measurements for baseline updates are provided below and described extensively in references cited here.

2.1 LIDAR

The lidar data acquisition plan is based on requirements to revisit the estimates of the emission factors in all forests during the crediting period for all 8 project and reference areas throughout the Pacific Coastal Region of Colombia. The current MRV plan covers all project areas and focuses on both intact (undisturbed at the baseline) and degraded forests as delineated in the baseline LULC map. The plan includes the minimum area required to allow an unbiased estimate of the forest biomass of the intact and degraded areas and avoids any exuberant data collection and processing costs for the project during the crediting period. The approach used in the start of the project for developing the baseline emission factors is applied for Lidar data acquisition and outlined in the new VCS tool VT0005 developed jointly by Terra Global Capital and the EcoGeoMap (VT0005: Tool for Measuring Aboveground Live Forest Biomass Using Remote Sensing). This approach includes the following steps:

1. Use the most recent VM0006 LULC to delineate the intact and degraded forests in all project areas.
2. The plan recommends a minimum total area of approximately 16,000 ha for the 8 project areas allowing for 8000 ha reference flights covering previously flown areas to detect any changes and/or examine accuracy of earlier estimates and a minimum of 8000 ha of new lidar data for a minimum of 1000 ha per project area for adjustment and updating the emission factors for degraded forests. The area covered for each project will be about 2000 ha for each baseline update. Any additional data over the project areas will improve the precision of the estimates of emission factors but will not be considered necessary.
3. Lidar data will be collected once before the first verification to update the emission factors for both degraded and intact forests and to document changes in terms of further degradation or regeneration. Lidar flights will be repeated every 10 years to update the baseline.
4. Emission factors will be calculated using the same lidar biomass estimation algorithm used in estimating the baseline emission factor (See VT0005) as long as the overall accuracy and point density of the lidar flights are approximately the same. The required specification of lidar data are provided in VT0005 and repeated in this document in Table 1. The lidar biomass allometry remain stable at each region and will not change significantly when using repeated measurements for monitoring.

5. In each project area, the project will select an existing lidar sample transect (minimum of 1000 ha) as the reference area to be flown again by lidar flights before the first verification and every 10 years thereafter.
6. Randomly select another point in degraded and intact forests in each project area to develop a randomly oriented single flight line covering approximately 1000 ha non-overlapping with the reference line. The random sampling transect is referred to new survey sample and will be performed using the Reverse Randomized Quadrat Recursive Raster (RRQRR) approach, a GIS based technique to generate a list of several thousand samples within a probability-based design framework and select one realization as the suggested sample for all project areas. We recommed to collect the new samples in the form of long transects (0.5 km x 20 km) for both as a cost-saving mechanism and for large area coverage. The long transect will be preferable to cover both intact and degraded areas in each project site. This will allow the project to extent the lidar flights to more than 20 km in case the monitoring funds allow for larger area coverage. The random selection of new flights will allow an unbiased estimate of changes for updating emission factors and avoiding any changes that may be avoided intentially in areas set aside for monitoring. The selection of random points for lidar flights can be performed prior the flights to avoid any a priori knowledge of light lines. Examples of lidar flights for three project areas area provided as examples in figure 2.
7. The requirements for lidar data acquisition in terms of number of points, calibration accuracy, and processing steps will follow the same earlier design (see GeoEcoMap Report # 2) and as recommended by VT0005.
8. Along with the lidar data, the airborne acquisition will include high-resolution digital imagery data to provide a visual verification of degraded areas and separation of potential intact forest stands from degraded areas within the lidar footprint.

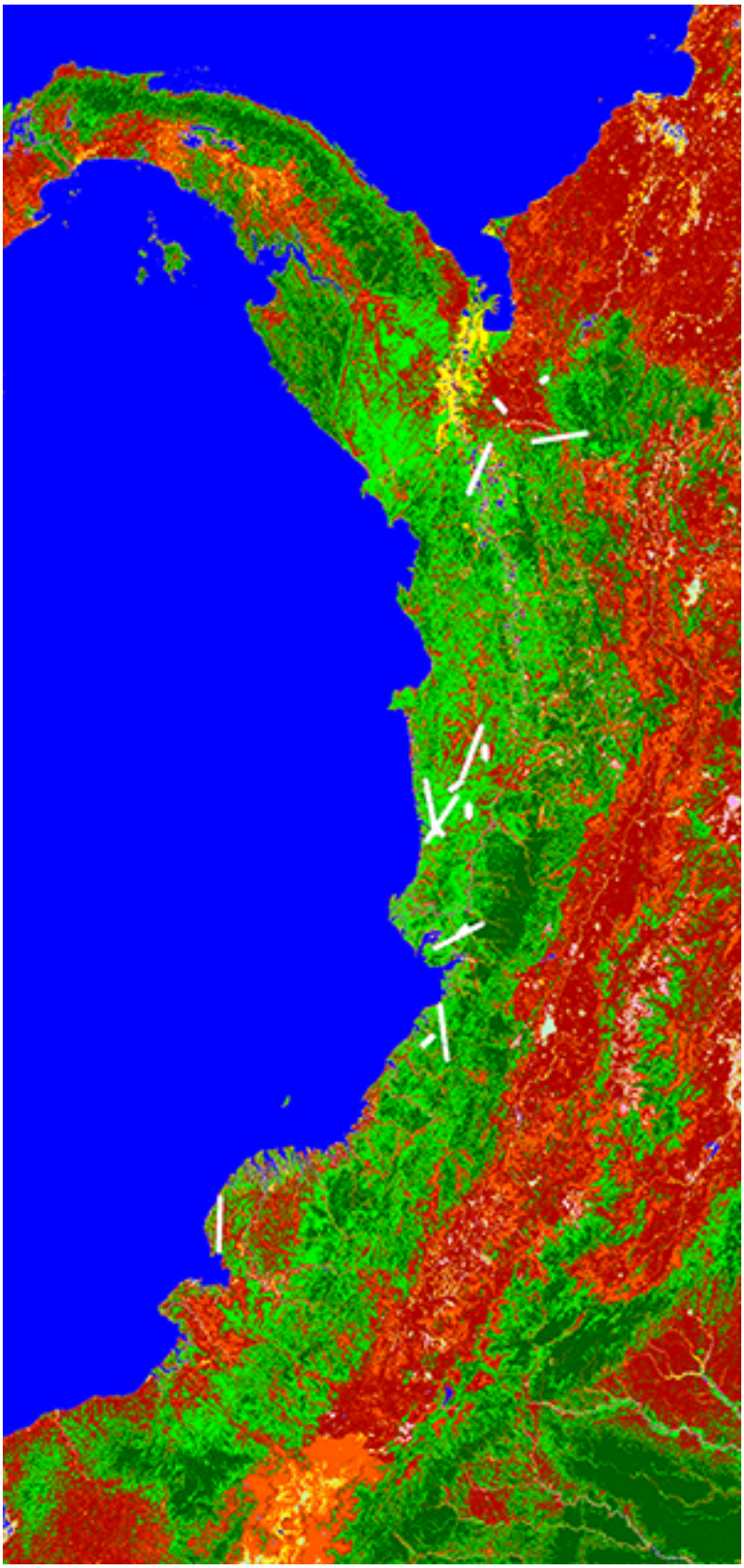

Fig. 2. Distribution of more than 16000 ha of lidar flight lines designed to update emission factors for degraded forests before the first verification event in 2016.

9. All lidar data must be acquired with maximum gain setting to get the best ground returns under dense forest canopy and vendors should provide information about the gain setting for the duration of the data acquisitions. In case the lidar vendor is different from the vendor acquired the baseline data, the requirements outlined in GeoEcoMap Report # 2 must be followed to allow comparable data quality for biomass estimation.

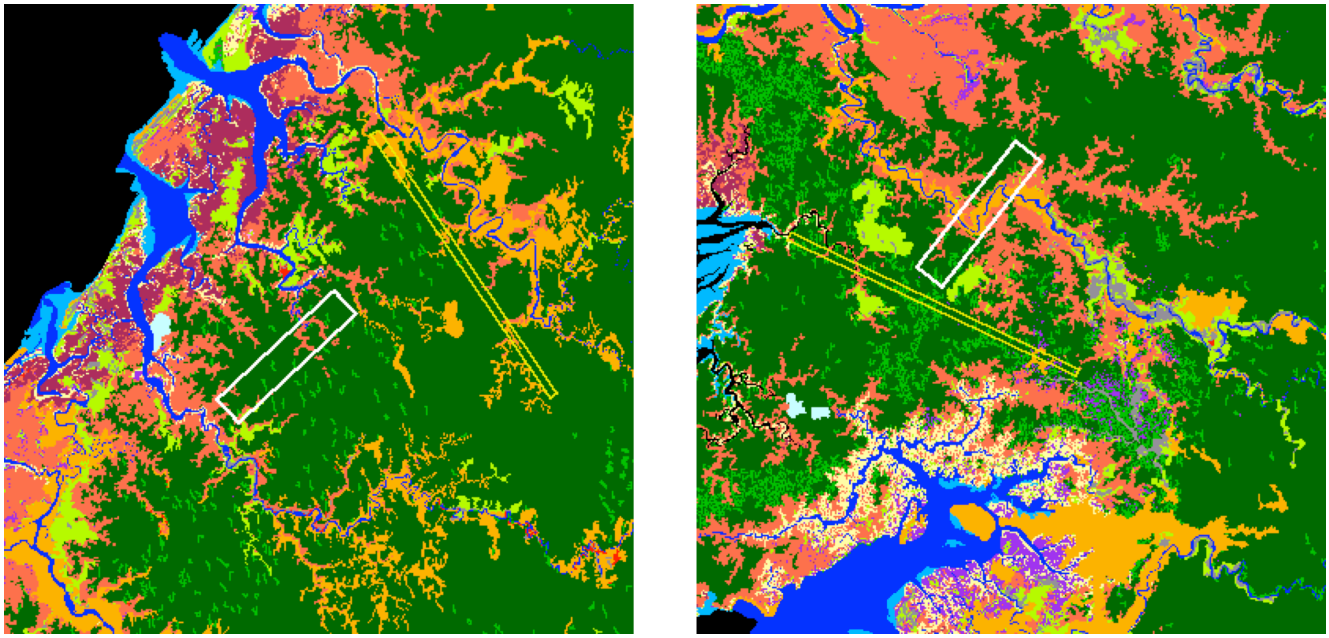

Fig. 2. Samples of lidar flights for each project area showing the one of the original lidar flight lines (1000 ha) in white and new flight line in yellow (1000 ha). The new flight line is selected randomly in the project area and in the forest class types (intact and degraded) to update the emission factors and to capture any changes in forest cover and carbon content due to small or large scale deforestation and degradation.

2.1.1 Lidar Flight

We recommend the following lidar flight lines as potential areas to be covered for to revise and update the emission factors for degraded forests and intact forests. The suggested flight lines will include a total area of 16000 ha covering 8 BioREDD project areas (Fig. 2.). All flights will be designed to provide the specifications below.

General Lidar Specifications		
Description		**Specifications**
1	Fundamental Vertical Accuracy (FVA) Requirements	Fundamental Vertical Accuracy (FVA) of the lidar point cloud data shall be assessed and reported using US NDEP/ASPRS guideline: The Fundamental Vertical Accuracy (FVA) Requirement for the Lidar Collection is: **AccuracyZ <= +/- 25 cm, @ 95% confidence interval (1.96 x RMSEz)** The Z accuracy is compared to GCP's on the same ellipsoidical height
2	Fundamental Horizontal Accuracy Requriements	The Fundamental Horizontal Accuracy (FHA) Requirement for the Lidar Collection and posting: **Accuracy X,Y <= +/- 30 cm, @ 95% confidence interval (1.96 x RMSExy)** The X,Y accuracy is compared to GCP's.

3	Sensor Requirements	The lidar sensor must: 1. Have been factory calibrated within 12 months prior to the collection (presentation of the calibration certificate will be required). 2. Detect multiple discrete returns, with a minimum of 4 returns for each outbound laser pulse. 3. Vertical Discrimination Absolute <= **4m** 4. Record the intensity of each return at >= 8-bit radiometric resolution 5. Max Scan Frequency >= 70Hz 6. Max Pulse Frequency >= 45kHz
4	Collection Requirements	1. The survey design must plan on: a. Single-Swath, 1st-Return Nominal Post Spacing (NPS) of 1.0 meters, and no coarser than 2.0 meters b. Scan angle not exceeding 40° Total FOV (+/-20° from nadir) 2. Flight line overlap must be **>40%.**
5	Lidar Flight Deliverables	1. Flight Plan: 2. As-Flown Data and Graphics (trajectories, speed, altitude, attitude, FOV, swath overlap, collection coverage) 3. GPS-IMU data 4. R-G-B raw frame images, 5. Flight Database 6. Instrument Calibration Report 7. Calibration of Instrument/GPS/IMU 8. Flight Logs

2.1.2 Lidar Processing

The project recommends the following requirements for data acquisitions and processing to allow for data quality similar to what was acquired during the baseline flight campaigns.

LiDAR Processing Steps: Point Cloud Specifications		
Deliverables		**Specifications**
1	Unclassified Point Cloud (Ellipsoidical)	1. All returns, all collected points, fully calibrated and adjusted to specified vertical datum, by swath. 1 file per swath, 2. Fully compliant LAS v1.2, point record format with all standard attributes including: a. Intensity values (native radiometric resolution). b. Return Number. c. Number of Returns d. Georeferencing information in all LAS file headers. e. GPS times recorded as adjusted GPS time, at a precision sufficient to allow unique timestamps for each pulse. 3. LASv1.2 deliverables 4. File naming should be discussed and decided later.
RGB Imagery Specifications		
Deliverables		**Specifications**
1	Digital Camera	Focal Plane - 39 MP full-frame-transfer CCD - 7162 x 5389 pixels (38,596,018 active pixels) - 6.8 um pixel pitch

		- Bayer array filter - Max frame rate 0.5 Hz (2.02 seconds per frame) - Dynamic range 12 bits - Maximum shift in boresight after removal and replacement of camera head = 0.5 pixel Exposure Control via - Gain 1, 2, 3, 4 - Exposure time >1/4000 sec - Automatic and manual modes - No aperture adjustment (fixed to f-4.0)
2	Photogrammetric Survey Deliverables	1. Flight Plan: 2. As-Flown Data and Graphics 3. GPS-IMU data 4. R-G-B raw frame images 5. Flight Database 6. Camera Calibration Report 7. Calibration of Camera/GPS/IMU 8. Flight Logs

The monitoring team will need to perform few post-processing steps to make the lidar data ready for development of biomass estimates. These include:

1. Create forest height map at the native resolution of lidar (e.g. 1-m) by creating CHM (canopy height model) from the difference between DSM (Digital Surface Model: the first return) and DTM (Digital Terrain Model: last return).
2. Use the CHM which represent the top canopy height at the lidar native resolution at 1-m to develop average mean top canopy height MCH at 50 m (0.25-ha) or 100 m (1-ha) to apply the lidar biomass models developed for the same resolution from relating the lidar metric and the ground data in the region.
3. Develop a raster forest biomass map at 0.25 ha or 1-ha spatial resolution.
4. In the case of mixed intact and degraded forest in the lidar coverage, separate the two by delineating areas of degraded forests using a combination of canopy cover estimate from lidar and visual interpretation of digital airborne color imagery.
5. Examine the changes in forest cover and biomass in reference lidar data and estimate degraded areas in the new survey lidar transect sample.
6. Both the degraded areas from changes in forest cover and the biomass are analyzed to provide estimates of percentage of area degraded or recovered from past degradation, and the new emission factors.
7. The high-resolution lidar surveys in reference and new survey sites will allow quantifying of minor degradation in intact forest class and continued degradation in degraded areas by detecting single tree removals or small scale infrastructure developments. The small scale degradation may or may not change the emission factor significantly for forest and degraded forest class but will be included in the LULC changes.

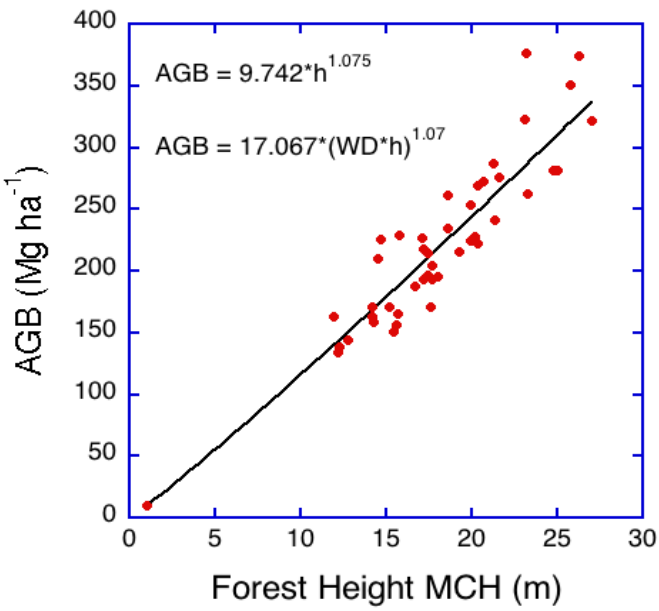

Fig. 3. Relation between lidar mean top canopy height and forest aboveground biomass derived from lidar measurements and 45 systematically designed ground plots in a degraded forest scene used for baseline estimation of emission factors.

The QA/QC guidelines proposed as part of the monitoring plan in PD section 8.1.3.1 verify the accuracy and consistency of lidar observations ensure the integrity of data collection, management of project databases and the database archival during the crediting period.

2.1.3 Lidar Models

The project will use the same lidar biomass model developed during the baseline lidar data analysis to estimate the biomass of all forest types and revise the baseline emission factors. This model was developed using the lidar data and ground plots as discussed in GeoEcoMap report #8&9 and the uncertainty report # 16.The model has the general form of:

$$AGB = a(WD \times h)^b + \epsilon$$

where WD represents the plot mean value of wood density in units of g cm^{-3}, h represents the mean top canopy height MCH in units of m, and $\epsilon \sim N(0, \sigma^2)$ represents the uncertainty in measurements or when observations deviate from a power-law by accounting for the heteroskedasticity. The model used in the baseline estimates are shown here for reference. This model is derived from the 45 sample plots at 0.25 ha with corrected geolocation errors.

2.2 LIDAR ESTIMATES OF CARBON STOCKS

Lidar flights will be used to estimate the aboveground carbon stocks in primary and degraded forests. Carbon stocks for other nonforest classes according to the VM0006 methodology such as nonforest wetlands, agriculture, pasture, settlements, and other nonforest types will remain fixed and will not change during the crediting period for all BioREDD projects. Carbon stocks in organic soil pool will not be included in the carbon accounting and will not be monitored throughout the entire crediting period.

2.2.1 Updating Carbon Stocks of Primary Forests

For intact or primary forests, the new surveys of lidar data along with the lidar biomass model as shown above will be used to update the carbon stocks of primary forests as outlined in GeoEcoMap report 8&9 during the first verification in 2016 and subsequent baseline updates. The new lidar imagery will be used to quantify the percentage for forest cover at 0.25 ha or 1-ha scales by using the definition of forests of trees > 5 m height for each 1 m lidar pixel. The carbon stocks for lidar for all pixels that fall greater than 70% cover will be used to estimate the mean and variance of carbon stocks for the lidar flights using the statistical model in GeoEcoMap report # 8&9 (section 8) and according to the VT0005 remote sensing methodology tool. The new carbon stocks for each project area will be used to update the carbon emission factors for primary forests.

For verification and monitoring events that occur between carbon stock updates using lidar measurement (i.e. at first verification and baseline updates), accounting for changes in primary forest carbon stock will be done using a model that conservatively underestimates the carbon stocks in primary forest. Subsequently at baseline updates, carbon stock in primary forest will be accurately updated using LiDAR remeasurement.

For monitoring events that don't use scheduled lidar flights, changes in carbon stocks will solely be measured by remote sensing techniques. In general, remote sensing approaches may not be able to detect selective and illegal logging where a small number of trees are extracted by local communities. For consistency with project documents and baseline measurement, we will rely on degradation as defined and detected in the baseline methods where canopy closure between 30-70% will define degraded forests and between 70-100% will define primary forests. Given that observed agents of degradation in the project area include selective logging that result in small changes in canopy cover, it becomes important to be able to account for degradation that does not result in a transition from primary forest to degraded forest according to the 70% threshold yet is degradation that significantly impacts the average carbon stock of primary forest. For this reason, a conservative model of primary carbon stocks is used to account for these non-detectable but potentially significant changes in forest carbon stock prior to LiDAR remeasurement and the accurate update of actual forest carbon stocks(Pearson et al. 2014).

To conservatively update the carbon stock in primary forest C^*_{PF} (tC/ha) between LiDAR remeasurement, the following model will be applied:

$$C_{PF}^{*} = C_{PF} \times [1 - f_{DG} \left(\sum A_{PF-DF} \right)]$$

where $f_{DG} \in [0, 1]$ is the fractional carbon loss, a function of the sum of all prior LULC transitions from primary forest to degraded forest $\sum A_{PF-DF}$ since the project crediting period start date.

Upon conservatively updating the carbon stock in the primary forest using the above model, the updated carbon stock is then applied to update the emission factors associated with primary forest transitions to other land covers used in monitoring and verification (section 3.1). These updated emissions factors increase over time as a function of f_{DG} and are conservatively applied to observed LULC changes in the project scenario to determine project emissions in primary forest, an overestimate.

The fractional carbon loss is assumed proportional to

$$f = \frac{\sum A_{PF-DF}}{A_{PF}} \times y$$

where y is the proportion of carbon lost from the forest canopy reducing from 100% to 70% (i.e. from primary forest to the upper bound of degraded forest). It is important to note the sum $\sum A_{PF-DF}$ is used across monitoring periods in order to continuously update the primary forest carbon stock.

The basis for this predictive model relies on the assumption that agents of degradation will treat areas of primary forest equally (i.e. areas between 70-100% canopy closure) when selectively logging. Given this assumption, the proportion of primary forest that transitions to degraded forest ($\sum A_{PF-DF} / A_{PF}$), which is detectable by remote sensing techniques, can be equally considered to be the proportion of primary forest impacted by degradation that did not produce a detectable change over the 70% threshold. In other words, we assume the degradation rate in the primary forest prior to reaching the class of degraded forest is constant; we observe the total area $\sum A_{PF-DF}$ transition from primary forest to degraded forest and we assume that an equal area $\sum A_{PF-DF}$ is transitioning within primary forest but not yet reaching the class of degraded forest (70% canopy cover).

Further conservatively assume that $y = \frac{C_{PF} - C_{DF}}{C_{PF}}$ so that

$$C_{PF}^{*} = C_{PF} \times \left[1 - \frac{(C_{PF} - C_{DF}) \times \sum A_{PF-DF}}{A_{PF} \times C_{PF}} \right]$$

2.2.2 Updating Carbon Stocks of Degraded Forests

The new carbon stocks for each project area will be used to update the carbon emission factors for degraded forests. The project will perform analysis of lidar data over the degraded forest in all project areas to revise the carbon stocks determined at validation. Lidar data along with the lidar biomass model as shown above will be used to update the carbon stocks of degraded forests as outlined in GeoEcoMap report # 8&9. The new lidar imagery will be used to quantify the percentage for forest cover at 0.25 ha or 1-ha scales by using the definition of forests of trees > 5 m height for each 1 m lidar pixel. The carbon stocks for lidar for all pixels that fall between 30% to 70% cover will be used to estimate the mean and variance of carbon stocks for the lidar flights using the statistical model in GeoEcoMap report # 8&9 (section 8) and according to the methodology tool VT0005. The comparison of the new estimates in old areas and new areas with previous estimates in old lidar areas will allow us to examine if the emission factors are changed and if the changes are due to estimation process or due to changes in forest cover as in degradation or regeneration of the degraded forests. Baseline estimates of emission factors for degraded forests will be revised for the project with new values once potential changes from forest changes have been accounted for. The new estimate of the emission factor will be revised and updated every 10 years according to the VCS

minimum requirements. This process will be repeated for all project area within the BioREDD region simultaneously to allow for cost reductions. For updating all other carbon pools, see section 2.3 or follow the approach outlined in GeoEcoMap report # 12.

2.2.3 Updating Other Carbon Pools

After updating the carbon stocks in the above ground live vegetation biomass as referred to aboveground organic matter of trees AGT, for primary and degraded forests, all other carbon pools can be automatically updated using the models and factors used for forests in the region and outlined in the GeoEcoMap report # 12. These pools include: 1. Aboveground non-tree organic matter AGNT. 2. Belowground organic matter BG, 3. Lying deadwood organic matter LDW, 4. Standing deadwood organic matter SDW, 5. Dead tree stump organic matter DTS.

2.3 EMISSION FACTORS FOR VERIFICATION

The baseline emission factors as outlined in the Project Description is valid until the first verification event when the baseline values will be revised using updated carbon stocks from lidar flights. For monitoring events and verifications that occur without lidar flights the conservative model presented in section 2.2 will be used to update emission factors resulting from forest transitions in lieu of lidar data.Additionally, the baseline emission factors will be revised every 10 years from the project start date per VCS minimum requirements using lidar data. The baseline revisions of LULC and emission factors will apply to the temporal boundary of the project, reference and leakage areas.

Data collection procedures in regards to revision of the baseline will include remote sensing and GIS techniques and any ground observations in terms of interviews and collaboration with the communities and local government or municipal officials. The project however, will rely solely on the remote sensing datasets on the extent and spatial location of all deforestation and degradation within the reference areas that cover both project and leakage areas. Other datasets used to substantiate aspects of the baseline with be from official government sources, peer reviewed publications, or other reputable sources.

2.3.1 Updating Emission Factors for Primary Forests

The emission factors for primary forest will be done for every verification and monitoring event. Two methods have been proposed using either lidar data or a conservative model as presented in 2.2 for the updating of above ground carbon stocks and thus emission factors. In years where lidar has been collected (i.e. first verification and baseline updates) the emission factors will be updated using revised carbon stocks from these measurements. In the case of verification without lidar measurements the carbon stock will be updated using a conservative model presented in section 2.2. Using these carbon stocks emission factors as a result of primary forest transitions will be updated.

According to the VM0006 methodology emission factors must also be updated during baseline updates. Lidar flights will be used during baseline updates to recalculate the carbon stocks and consequently emission factors for primary forests will also be updated.

2.3.2 Updating Emission Factors for Degraded Forests

The project will perform analysis of lidar data over the degraded forest in all project areas to revise the baseline emission factors as determined during validation. The new estimate of the emission factors will be revised during the first verification and updated every 10 years according to the VCS minimum requirements for baseline updates. For any verification that may occur between the baseline updates, the project will use the updated baseline emission factors and the transitions between degraded forests and non-forest class types for carbon accounting. Any further degradation of degraded forests between 30-70% forest cover will not be accounted for between the baseline updates. The updated baseline emission factors represents the average carbon stocks of forests falling

under the 30-70% cover according to the lidar derived forest canopy cover and any changes in terms of further degradation or regeneration will remain within the same range unless it will be transitioned to forest or non-forest class types.

2.3.3 Table of Emission Factors for Project Areas

The emission factors determined at validation are presented in the table below for each BioREDD+ project in the Colombian Pacific Coast.

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	154.3	2.714	43.34	2.159	3.235	0.3436	12.79	0.5433	3.660	0.2861	2.056	0.4501	76.86	5.384
	2	53.98	3.708	16.88	2.757	2.670	0.4172	17.80	1.112	6.256	0.7260	2.904	0.9425	72.87	3.901
	3	15.78	4.469	8.745	3.426	1.673	0.5028	11.16	1.341	1.334	0.7870	1.798	1.122	59.55	5.189
	4	20.51	2.477	10.16	1.919	1.665	0.2786	11.10	0.7430	1.016	0.4006	1.778	0.6166	64.64	5.412
	5	15.96	4.327	5.709	3.365	1.979	0.4868	0.000	0.000	0.000	0.000	0.000	0.000	47.29	4.368
	6	6.560	0.9062	2.587	0.7711	0.7968	0.1019	0.000	0.000	0.000	0.000	0.000	0.000	54.30	4.089
	7	17.96	1.311	6.341	1.160	0.5389	0.1475	0.000	0.000	0.000	0.000	0.000	0.000	17.82	1.557
CDD	1	175.1	3.247	48.52	3.199	2.841	0.7648	17.35	1.209	3.303	0.6352	1.809	1.001	39.23	5.384
	2	36.98	2.414	12.06	3.939	1.109	0.5716	7.396	1.524	2.142	0.8865	1.190	1.273	38.88	3.901
	3	16.97	2.640	6.029	2.166	0.9592	0.2970	6.394	0.7921	1.417	0.3479	1.012	0.6444	40.11	5.189
	4	8.501	4.459	3.258	3.404	1.455	0.5016	9.700	1.338	1.768	0.8229	1.559	1.124	42.64	5.412
	5	10.82	1.891	4.040	1.595	0.3247	0.2128	0.000	0.000	0.000	0.000	0.000	0.000	42.32	4.368
	6	0.2940	0.09000	1.631	0.4634	0.008820	0.000	0.000	0.000	0.000	0.000	0.000	0.000	39.16	4.089
	7	34.03	3.481	11.20	2.782	1.021	0.3916	0.000	0.000	0.000	0.000	0.000	0.000	43.44	1.557
SUPP	1	164.8	3.489	45.97	3.065	3.163	0.4947	16.64	0.7824	3.619	0.3889	2.011	0.6446	44.96	5.384
	2	68.05	4.697	20.90	3.596	2.028	0.5284	14.44	1.409	4.376	0.8251	2.192	1.179	57.47	3.901
	3	10.41	3.875	3.901	3.093	0.7623	0.4360	5.082	1.163	1.259	0.5959	0.8095	0.9587	59.01	5.189
	4	5.847	3.672	2.335	2.891	1.525	0.4131	10.17	1.102	1.830	0.5705	1.632	0.9101	49.48	5.412
	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6	8.313	0.6642	3.194	0.6284	0.2494	0.07473	0.000	0.000	0.000	0.000	0.000	0.000	52.96	4.089
	7	26.70	4.387	9.022	3.396	1.401	0.4936	0.000	0.000	0.000	0.000	0.000	0.000	37.14	1.557
BMF_ACAPA	1	168.6	1.664	46.90	3.126	1.954	0.6526	16.02	1.032	1.946	0.4861	1.232	0.8452	72.29	5.384
	2	78.30	4.303	23.62	2.620	1.224	0.3681	18.35	0.9815	2.057	0.4751	1.301	0.8055	77.24	3.901
	3	12.94	3.099	4.734	2.543	0.8381	0.3487	5.587	0.9298	1.266	0.4097	0.8856	0.7568	81.96	5.189
	4	17.65	2.656	6.242	2.145	1.129	0.2989	7.530	0.7969	1.760	0.3691	1.195	0.6516	78.14	5.412
	5	15.30	2.139	5.496	1.799	0.4589	0.2407	0.000	0.000	0.000	0.000	0.000	0.000	47.29	4.368
	6	7.283	0.5390	2.839	0.4973	0.2185	0.06063	0.000	0.000	0.000	0.000	0.000	0.000	72.10	4.089
	7	22.66	1.955	7.798	1.683	0.6799	0.2200	0.000	0.000	0.000	0.000	0.000	0.000	85.86	1.557
CAJAMBRE	1	158.8	2.754	44.48	2.965	3.302	0.4004	13.06	0.6332	3.804	0.3211	2.101	0.5226	60.55	5.384
	2	69.33	4.604	21.09	3.467	2.830	0.5179	18.87	1.381	6.974	0.8613	3.091	1.164	57.67	3.901
	3	17.18	3.571	9.166	2.855	1.115	0.4017	7.435	1.071	1.871	0.5398	1.185	0.8818	65.46	5.189
	4	28.53	2.920	12.51	2.226	1.756	0.3285	11.71	0.8760	3.307	0.5083	1.880	0.7325	61.62	5.412
	5	24.09	3.525	8.233	2.668	2.223	0.3966	0.000	0.000	0.000	0.000	0.000	0.000	47.29	4.368
	6	5.750	0.7001	2.301	0.5567	0.1725	0.07000	0.000	0.000	0.000	0.000	0.000	0.000	44.40	4.089
	7	5.800	0.1168	2.318	0.1147	0.1740	0.01314	0.000	0.000	0.000	0.000	0.000	0.000	17.81	1.557
CONCOSTA	1	153.4	2.170	43.12	2.695	3.183	0.4835	16.82	0.7645	3.646	0.3831	2.024	0.6304	54.53	5.384
	2	81.77	4.339	24.43	3.308	2.165	0.4881	24.34	1.302	4.717	0.7713	2.341	1.090	61.74	3.901
	3	15.76	3.184	8.740	2.618	0.7729	0.3582	5.153	0.9552	1.169	0.4173	0.8167	0.7771	76.72	5.189
	4	22.16	3.144	10.65	2.497	1.415	0.3537	9.431	0.9432	2.475	0.4690	1.507	0.7762	52.12	5.412
	5	23.51	2.835	8.056	2.369	0.7053	0.3190	0.000	0.000	0.000	0.000	0.000	0.000	61.48	4.368
	6	3.273	0.3158	1.393	0.3432	0.09817	0.03553	0.000	0.000	0.000	0.000	0.000	0.000	63.11	4.089
	7	16.48	1.713	5.873	1.483	0.4945	0.1927	0.000	0.000	0.000	0.000	0.000	0.000	67.55	1.557
MUTATA	1	176.0	3.863	48.72	3.247	3.578	0.5062	14.15	0.8005	4.347	0.4431	2.285	0.6664	61.34	5.384
	2	71.79	5.589	21.76	4.154	3.054	0.6287	20.36	1.677	7.965	1.129	3.352	1.425	99.52	3.901
	3	16.35	4.520	8.917	3.403	1.690	0.5085	11.27	1.356	3.368	0.8615	1.817	1.145	60.97	5.189
	4	29.79	4.652	12.87	3.494	2.244	0.5234	14.96	1.396	5.004	0.8992	2.431	1.180	73.18	5.412
	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6	14.38	4.447	8.321	3.668	1.031	0.5003	0.000	0.000	0.000	0.000	0.000	0.000	45.04	4.089
	7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
RIO_PEPE_ACABA	1	168.3	3.722	46.82	2.926	2.874	0.4596	11.36	0.7268	3.118	0.3656	1.821	0.5997	20.72	5.384
	2	52.51	3.901	16.47	2.903	2.625	0.4389	17.50	1.170	6.131	0.7611	2.855	0.9912	18.33	3.901
	3	15.88	3.786	8.777	2.905	1.527	0.4259	10.18	1.136	2.830	0.6547	1.633	0.9488	19.30	5.189
	4	27.70	3.110	12.27	2.369	1.731	0.3498	11.54	0.9329	3.263	0.5451	1.853	0.7806	19.39	5.412
	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6	16.96	0.9141	12.05	0.7433	1.109	0.1028	0.000	0.000	0.000	0.000	0.000	0.000	16.02	4.089
	7	32.55	3.560	10.76	2.700	1.577	0.4005	0.000	0.000	0.000	0.000	0.000	0.000	15.72	1.557

3 Monitoring Methods

The project implementation is monitored, including the project boundary, the area prevented from land use change and any activities that reduce carbon stocks or result in emissions in the project area over the crediting period. All project boundaries in the BioREDD program are functionally discrete units with distinct reference regions and buffer zones for leakage and do not require any additional regions for monitoring for emissions.

Stratification of the project area or in this case the LULC class types according to VM0006 is monitored periodically because two different LULC may become similar enough in terms of carbon to justify their merging. The *ex-post* classification considers monitoring of the project strata to verify the applicability of the *ex-ante* LULC, and variables that influence each class. The *ex post* classification procedures facilitate cost-effective, consistent and accurate monitoring of carbon stock changes of the project during the crediting period.

The overall monitoring process includes:

1. Monitoring LULC classes before the first verification for any potential adjustment of reference and leakage areas.
2. Monitoring LULC frequently before any verification cycle during the crediting period and/or every 10 years after the first verification according to the VM0006 methodology for estimating transitions of forest and degraded forests to nonforest classes (emissions) and potential transition of degraded and nonforest classes to forest class (removals). Monitoring frequency of LULC will depend on the verification cycles. If less than 10 years, LULC will be monitoring before every verification. However, the emission factors will be updated only every 10 years.
3. Monitoring LULC with airborne lidar data before the first verification and every 10 years thereafter according to VM0006 methodology to quantify the small-scale degradation (illegal logging or other selective extraction of trees) in intact forest, continuing degradation in degraded forests or any regeneration causing LULC class change.
4. The methodology for LULC follows the same approach adopted for developing baseline LULC maps according to the VM0006 methodology by including the classification of Landsat time series and potential radar imagery to capture transitions of LULC within the project, reference, and leakage areas.

3.1 MONITORING LAND USE CHANGE

Stratification or LULC of the project area is monitored periodically because two different LULC classes may become similar enough in terms of carbon to justify their merging. The *ex-post* LULC considers monitoring of the project strata to verify the applicability of the *ex-ante* LULC, and variables that influence the strata. The *ex post* LULC procedures facilitate cost-effective, consistent and accurate monitoring of carbon stock changes of the project during the crediting period. In the BioREDD regions, we developed the LULC according to the VM0006 methodology and calculated the carbon stocks and emissions factors. The baseline lidar approach was based on random sampling of a large area of the region that allowed carbon assessments based on stratification and LULC classes. In addition, a wall-to-wall map of the carbon stocks and pools of the BioREDD region was developed that encompasses project, reference, and leakage areas This allows for the development of monitoring procedures at different levels and for potential changes to *ex post* LULC and emission factors, if cost and efficiency become important components of future monitoring.

We included the minimum of six IPCC LULC classes (Forest Land, Crop Land, Grassland, Wetlands, Settlements, and Other Land) in the LULC class definitions and historical deforestation and degradation analysis as required by VM0006 methodology. The definitions of these classes are consistent with Chapter 2 of the IPCC GPG-LULUCF 2003 and are summarized in GeoEcoMap Task 7. We found no need to define more region-specific LULC classes than what is recommended by IPCC. However, we added a degraded forest class as a key class for the region and for the BioREDD project.

3.1.13.1.1 Data Sources

1. The Landsat 8 dataset at 30 m resolution and 15 m panchromatic imagery for the entire BioREDD project area for the period before any verification event during the crediting period. Though Landsat imagery only provides information on the top of the canopy, its relatively high resolution allows easy discrimination of forest and non-forest classes, and the discrimination of degraded forest, particularly immediately after the degradation. Multiple date imagery must be acquired to have relatively cloud free data over the project areas on an annual basis.

2. ALOS-2 PALSAR L-band radar satellite data at dual polarization (HH and HV) that have started to collect data starting in 2014. The cross-polarized long-wavelength radar data provides information on vegetation structure and can thus differentiate intact, degraded and deforested land. Radar data has the additional advantage that it is unaffected by cloud cover and can help improve the classification of Landsat data over areas contaminated by clouds and haze. It is recommended to collectALOS-2 PALSAR data over the BioREDD project regions before any verification event during the crediting period. It is recommended to have more than one image for each region to allow for any changes due to environmental factors such as soil moisture. The project may develop a plan with the Japanese Space Agency for acquiring data at a reduced cost.
3. Other potential data sets can be included in the analysis such as Terra-XSAR at 6 m resolution for detecting small-scale changes of forest canopy cover, and high-resolution commercial optical imagery at 1-5 m resolution for detecting degradation. Any future satellites with potential monitoring capacity as the above moderate or high resolution data can be used to continue monitoring LULC during the crediting period.
4. Airborne lidar data sampling approach as designed for revising the baseline emission factors. Lidar imagery over the reference sample and new randomly selected survey samples will allow detecting changes of forest cover in the permanent site and any changes in the project or reference areas that may be due to small scale degradation that may not be captured by the Landsat and radar imagery. The new lidar surveys will be randomly located in the project or reference areas in the forest classes to avoid any a priori knowledge of the monitoring sites for reduce any effects of intentional avoided deforestation and degradation.

3.1.2 Data Processing

Standard processing techniques are applied for preparing the data sets for LULC classification. The processing steps are separated by satellite sensor.

For Landsat data the following processing steps are used:

1. To reduce the effect of cloud, cloud shadow, and haze on Landsat imagery, the VM0006 methodology recommends the use of several Landsat images acquired a year before each verification event to allow for a relatively cloud free composite image.
    a. All Landsat imagery will go through the process of atmospheric correction using the most recent models in image processing software as in ENVI/IDL or through several freely available models. The atmospheric corrections will produce reflectance products from Landsat bands. The reflectance products will be orthorectified. The cloud mask analysis includes the segmentation of clouds in the imagery using ENVI segmentation algorithm by thresholding the reflectance values in RED and Near IR frequencies. Similarly cloud shadows can be masked using a similar segmentation approach. Cloud and cloud shadow can be separated using other approaches such as the maximum-likelihood classification.
    b. One of the key problems in Landsat imagery is the impact of the haze in the data. In general, haze can impact the forest class more than any other class, causing it to be confused with nonforest classes. Often haze will allow classification through visual interpretation but introduces large uncertainty in automatic LULC classification. Using image data from several dates, the cloud and

haze effects can be removed by automatically replacing the pixels with haze by other haze free reflectance.

c. Optical Image data can be orthorectified for removal of terrain distortions by making use of the surface digital elevation model and standard orthorectification routines as used in ENVI software. However, Landsat 8 along with all Landsat level series imagery are corrected for terrain distortions and already orthorectified.

d. Lidar data processing will follow the protocols outlined in baseline assessments in GeoEcoMap reports 8 and 9. All lidar images will be processed to create canopy height model at 1-m grid cells and aggregated to 50 m or 100 m to create forest height metrics such as mean top canopy height and percent of canopy cover that can be compared with the height metrics and forest canopy cover data from earlier surveys to detect changes.

2. Before classification, image data can be combined and mosaicked to create one set of imagery with the least cloud cover.

For ALOS PALSAR data we will use the following processing steps:

1. ALOS PALSAR image data ordered for the BIOREDD region must include basic processing steps including terrain correction, and orthorectification. These options exist when ordering the data. Most common ALOS PALSAR data will be from FBD mode that includes two polarizations. However, if raw data are ordered, the terrain correction and orthorectification can be performed using free online packages provided by JAXA (Japanese Space Agency) or NASA such as MapReady Remote Sensing Tool Kit: https://www.asf.alaska.edu/data-tools/mapready/
2. Georeferencing can be performed using external high resolution data or other image data used for the analysis such as Landsat images to allow for accurate estimation of area of deforestation and degradation and any changes from baselines. The improvement of georeferencing can be performed by collecting tie points between the ALOS PALSAR and Landsat imagery or other available high resolution imagery to reduce the georeferencing errors to less than one pixel. The number of tie points can be approximately 10-20 spread over the entire scene and following standard remote sensing protocols.
3. Single ALOS PALSAR imagery can only cover approximately 100 km x 100 km areas. To cover the entire project area, multiple PALSAR imagery can be acquired, processed, and mosaicked to produce a wall-to-wall image of the project, leakage, and reference areas. Image mosaic will be projected using any standard GIS image projections.
4. ALOS PALSAR classification process for any LULC types can be performed using standard methods, such as maximum likelihood classification, provided in any GIS and remote sensing tool kits or software such as ENVI.
5. To apply ALOS PALSAR data for any automatic change detection approach may require development of the use of polarization metrics as provided in GeoEcoMap report 13. To develop this metric we focused on dual-polarization SAR data provided at HH (Horizontal transmit and Horizontal receive) and HV (Horizontal transmit and Vertical receive) radar backscatter intensities. The Radar Forest Degradation Index (RFDI) is defined as the normalized ratio of the two radar polarization channels, given by:

$$RFDI = \frac{HH - HV}{HH + HV}$$

where the backscatter intensities are in linear units (m^2/m^2). The value of RFDI varies between 0 and 1, as even in most topographically complex terrains HH is always larger than HV backscatter. For ALOS PALSAR FBD mode data, the geometry and incidence angle do not vary over SAR pixels, allowing temporal analysis of RFDI without concerns for changes in geometry and incidence angle or any other image characteristics.

3.1.3 LULC Classification

The mosaics are first classified into 5 classes: intact high-biomass forest, secondary/degraded/lower biomass forest, non-forest (grasslands, croplands), cloud, and cloud shadow. These classes are chosen based on detailed visual analysis of the imagery and comparisons to the Corine Ecosystem Map (IDEAM) and Google Earth Imagery, to decide which classes are easily and consistently distinguishable using Landsat. In particular it should be noted here that the "Degraded/Secondary forest" class in Landsat differs from the "Degraded Forest" class described above for PALSAR – as Landsat cannot penetrate the canopy fewer classes can be distinguished, and it is likely that this class in Landsat includes undisturbed but lower biomass forest, such as flooded vegetation or dwarf forests. The intact forest and non-forest classes seen by Landsat and PALSAR should be readily comparable.

The classifications are performed using a Support Vector Machine classifier, using at least 25 training regions chosen by eye and in consultation with experts and high resolution optical and lidar imagery for each class. The previous classifications all have had user accuracies in excess of 97 % when tested against the input data, which is well above the 90 % level normally used to test the acceptability of a classification to be used for a land-use change analysis (GOFC-GOLD, 2012).

If a mosaic has cloud cover over 30 % of its area, normal comparisons in terms of total area, as performed for PALSAR, are not appropriate here. Instead, only areas, which are cloud free in mosaic pairs can be compared. A mask is created for any pixel that is cloud or cloud shadow in either image, in order to remove effects of haze a 2 pixel buffer is applied to this mask, and the mask is then used over both images. These provide two sets of comparison images that can be used to calculate the deforestation and degradation rates from the benchmark image to the images used for verification.

Despite cloud-cover limitations, the Landsat data is able to provide a long-term view of rate of deforestation.

To perform the analysis with all recommended VM0006 classes, the non-forest or deforested classes are further divided into anthropogenic and natural classes. These include grasslands and croplands for anthropogenic classes and wetlands and other lands as natural classes. To develop classification, we mask out all non-forest classes within the image mosaics and develop new training areas using the IDEAM Corine ecosystem map, contextual image analysis for croplands, and radar and Landsat signal analysis. The final map should include 8 classes including the water bodies. The advantages of the two stage classification are: 1) to accurately separate the intact, degraded, and non-forest classes in the first stage given the quality of images and remaining noise from haze and shadow. These primary classes are important for the LULC transition analysis, and 2) to focus on non-forest vegetation classes and use the signal characteristics more efficiently to separate the class types.

The final maps for the deforestation and degradation analysis are developed for each period with 8 classes (intact forest, degraded forest, grassland, croplands, wetlands, settlements, other land, water). The ALOS PALSAR images are then combined classification with the LULC map to improve the final classification and in turn improve the transition of classes between the periods. For every pair of subsequent images in the monitoring period, we calculate the area of each land transition and report the results in a LULC and forest transition matrix. Note that for deforestation, lands should have been without forest cover for longer than the period defined as temporarily un-stocked. Likewise, for degradation, lands must have been in the smaller carbon stock density stratum for at least 3 years. An appropriate temporal filter is applied to ensure that only land that meets the three-year condition is designated as degradation. The filter is basically visual interpretation of pixels in subsequent Landsat imagery to confirm any areas of deforestation and degradation. After calculating the area of transitions between LULC classes between the benchmark and the monitoring period, combine any forest (intact or degraded) to non-forest (grasslands, croplands, settlements, other lands, wetlands) transition and classify it as deforested area. All intact forest pixels changing to degraded forest class are considered part of the degradation class. The transitions to secondary forests are included by accounting for all pixels that transition from the non-forest to degraded forest class in the next period image.

3.1.4 LULC Change Analysis

3.1.4.1 Calculating Accuracy and Uncertainty

Monitoring Deforestation, Natural Disturbance, and Leakage

To ensure consistency and quality results, spatial analysts carrying out the imagery processing, interpretation, and change detection procedures will strictly adhere to best practices and good practice guidelines, when using the alternative method for quantifying deforestation. All data sources and analytical procedures will be documented and archived (detailed in section 3.1.4.2 below).

Accuracy of the classification will be assessed by comparing the classification with ground-truth points or samples of high resolution imagery. Any data collected from ground-truth points will be recorded (including GPS coordinates, identified land-use class, and supporting photographic evidence) and archived. Any sample points of high resolution imagery used to assess classification accuracy will also be archived. Samples used to assess classification accuracy should be well-distributed throughout the project area (as far as is possible considering availability of high resolution imagery and/or logistics of acquiring ground-truth data), with a minimum sampling intensity of 50 points each for the forest and non-forest classes.

The classification will only be used in the forest cover change detection step if the overall classification accuracy, calculated as the total number of correct samples / the total number of samples, is equal to or exceeds 90%.

All data sources and processing, classification and change detection procedures will be documented and stored in a dedicated long-term electronic archive.

Information related to monitoring deforestation maintained in the archive will include:

1. Forest / non-forest maps as well as LULC change maps;

2. Documentation of software type and procedures applied (including all pre-processing steps and corrections, spectral bands used in final classifications, and classification methodologies and algorithms applied), if applicable; and
3. Data used in accuracy assessment - ground-truth points (including GPS coordinates, identified land-use class, and supporting photographic evidence) and/or sample points of high resolution imagery.

Quality control procedures related to monitoring leakage include conducting a review of the current literature at least every 5 years to source information on the area of the monitoring parameters MANFOR, PROTFOR, and TOTFOR. Further, participatory rural appraisals used to assess the length of time people have been living in the project area and leakage belt will be implemented by personnel with experience conducting community surveys in rural Brazil.

Personnel involved in the revising of the baseline will have detailed knowledge in regards to spatial modeling and land use change and deep familiarity with REDD methodologies. Remote sensing data used will include officially published dataset, or classified imagery, which meets accuracy assessment requirements as laid out in the VM0006 methodology.

3.1.4.2 Data Archiving

Data archived will be maintained through at least two years beyond the end of the project crediting period. Given the extended time frame and the pace of production of updated versions of software and new hardware for storing data, electronic files will be updated periodically or converted to a format accessible to future software applications, as needed.

4 Organization

4.1 ROLES & RESPONSIBILITIES

Role	Responsibilities	Competencies
Project Liaison	Oversight of the project Direction of forest, community, and monitoring experts Oversight of monitoring team training Review compliance with QA/QC procedures Report monitoring results to project proponents and assist in preparing monitoring and implementation reports	At least a bachelor's degree or equivalent Experience managing teams Experience working in the same region or country as the project Has a language in common with all subordinate managers
Lidar Carbon Monitoring Expert	Direct lidar analysts with statistical carbon calculation expertise Train lidar and carbon monitoring teams if necessary Consolidate data carbon estimates and update of baseline carbon emission factors factors, prepare measurement data, estimates, and reports	At least a master degree with extensive lidar remote sensing and forest biometry skills with extensive experience in statistical analysis on carbon estimates and uncertainty analysis. Experience managing teams and leading airborne lidar inventory
LULC Remote Sensing Expert	Direct remote sensing analysts and Lidar flight operations Consolidate and prepare LULC change monitoring reports Perform technical remote sensing analysis	At least a bachelor's degree in remote sensing (preferably master's degree) with extensive remote sensing experience Experience managing teams

4.2 ORGANIZATIONAL STRUCTURE

4.2.1 The MRV system–management architecture

***The MRV Section**:* To manage the different functions of the MRV system, a centralized management office is proposed. This office can be located in either one of the government offices such as IDEAM, local NGOs working with the REDD project, or any other government or private institutions. Its main objective is to organize and manage the MRV experts at the national and local level, in order to maintain the MRV system and promote data dissemination. The same MRV Section to be established for the national MRV will be responsible for executing MRV at the project level and building capacity of the relevant stakeholders to perform the tasks. In the BioREDD program, there are several projects within the same geographical regions. One or all of the projects can have one single management structure and unit. The MRV Section is subdivided in to four independent but strictly connected units:

1. Database/IT/Metadata Unit (DBM)
2. LULC Remote Sensing/GIS Unit (RS)
3. LiDAR Carbon Monitoring Unit (LCM)
4. Reporting Unit (REP).

Each unit has its own experts and IT software applications. An MRV Coordinator will manage the MRV Section.

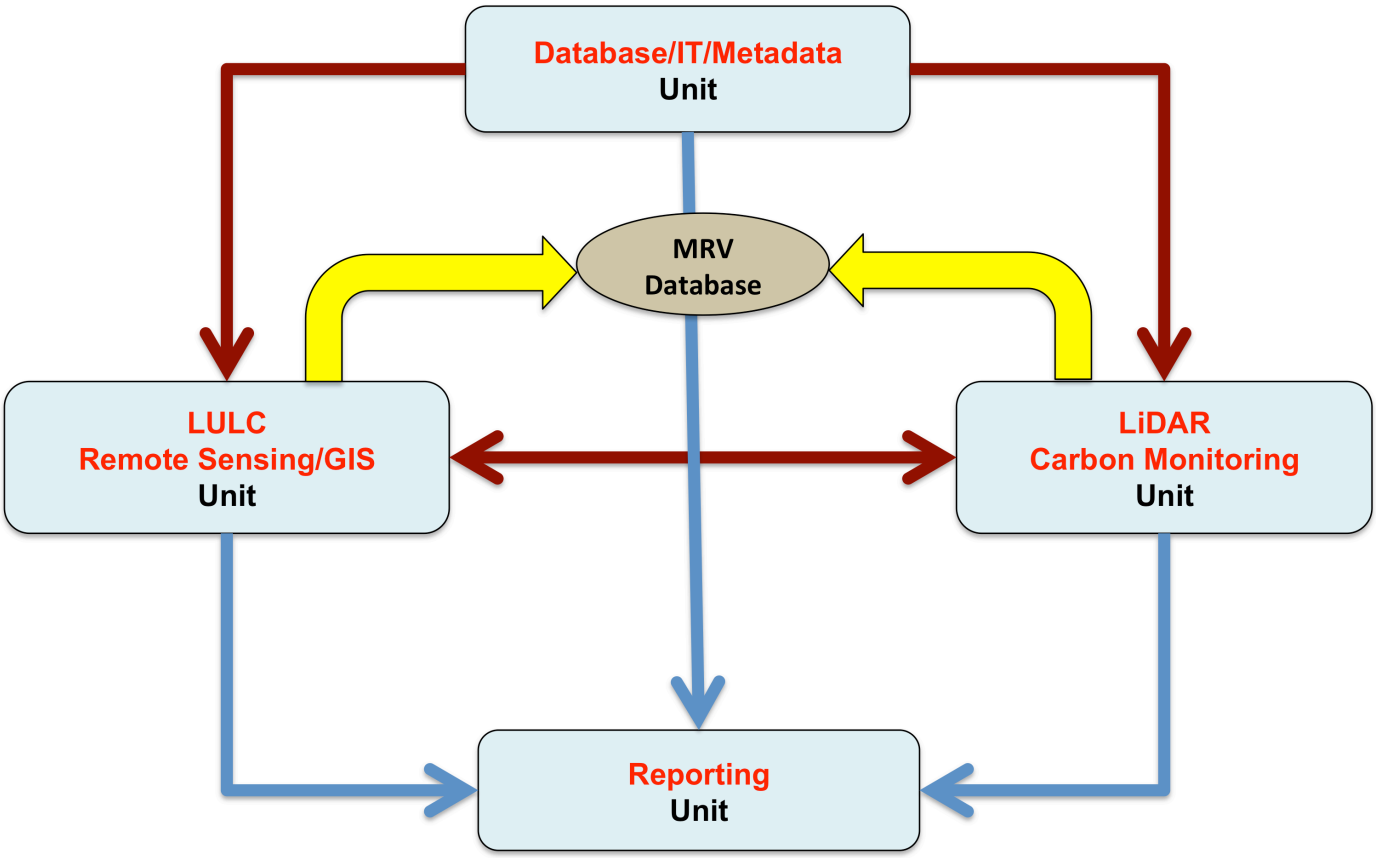

Fig. 4. Diagram showing the MRV units and the connections between measurement units, reporting unit and the MRV database units.

4.2.1.1 LULC Remote Sensing / GIS Unit (LRS)

The main objective of the LULC RS Unit will be image processing and analysis to produce Land Use/Land Cover classification layers and perform GIS editing and analysis to ensure data integrity in the monitoring and reporting (MRV in general) database. Multi-temporal satellite images, DEM and eventually other ancillary data will be used to identify change detection in forestry classes. Once LULC layers have been produced and validated, they will be uploaded into the monitoring database. Graphs and tabular data should be provided to the Reporting Unit upon periodical requests. This Unit, which should include two experts, could also take advantage of technical support from the REP and FIN Unit for specific tasks.

4.2.1.2 Lidar Carbon Monitoring Unit (LCM)

The main objective of the LCM unit will be to collect airborne lidar surveys before the first verification and every 10 years thereafter to update the baseline carbon emission factors for intact and degraded forests. In the BioREDD project, the LCM is responsible for performing any necessary post-processing of lidar data, develop height metrics, and use the lidar and forest aboveground biomass model developed for baseline estimates to compute new estimates of carbon stocks and uncertainty in intact and degraded forests. In addition, the airborne lidar data and potential airborne spectral imagery will be used to quantify the changes associated with small scale degradation from selective and illegal logging. The unit should include expertise to enforce the requirements for lidar observations as outlined in this report and have the statistical skills to estimate the new carbon stocks and uncertainty for forest class types and update all carbon pools outlined in GeoEcoMap report # 12. The Unit could also take advantage of technical support from the RS unit and other units for specific tasks. Graphs and tabular/aggregated data should be provided to the Reporting Unit upon periodical requests. The human resources

needed to manage this unit include one expert for lidar carbon calculation and potential resource sharing with the RS unit for lidar processing and analysis.

4.2.1.3 The Reporting Unit (REP)

This Unit provides periodic standard MRV reports (consistent with the reporting requirements outlined in the UNFCCC guidelines and the VM0006 methodology) for dissemination of aggregated data and information, collecting the necessary info by the other three units. Reporting is a key element of MRV because it provides the means by which, in a future REDD+ mechanism, the performance of the project will be assessed compared to its commitments or reference scenario, and therefore will represent the basis for assigning incentives. One REDD MRV expert is needed to manage this unit.

References

Pearson, T. R., Brown, S., & Casarim, F. M. (2014). Carbon emissions from tropical forest degradation caused by logging. *Environmental Research Letters*, *9*(3), 034017.