FORESTRY COMMISSION

HSBCP
HWANGE SANYATI BIOLOGICAL CORRIDOR PROJECT

FOREST INVENTORY FIELD MANUAL AND ACTIVITY DATA FOR REDD+ MRV

NGAMO AND SIKUMI REDD+ PILOT PROJECT

*Hwange Sanyati Biological Corridor Project*

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1.0 Introduction

This document contains a description of the measurement procedures for the estimation of biomass and carbon stocks in Ngamo and Sikumi Forest Reserves for the purpose of REDD+. It describes how the samples will be selected and identified in the field and how measurements shall be conducted and recorded.

2.0 Sampling design

The type of the proposed forest inventory is qualified as "stratified random sampling". Firstly the two forest areas will be stratified according to vegetation cover types.
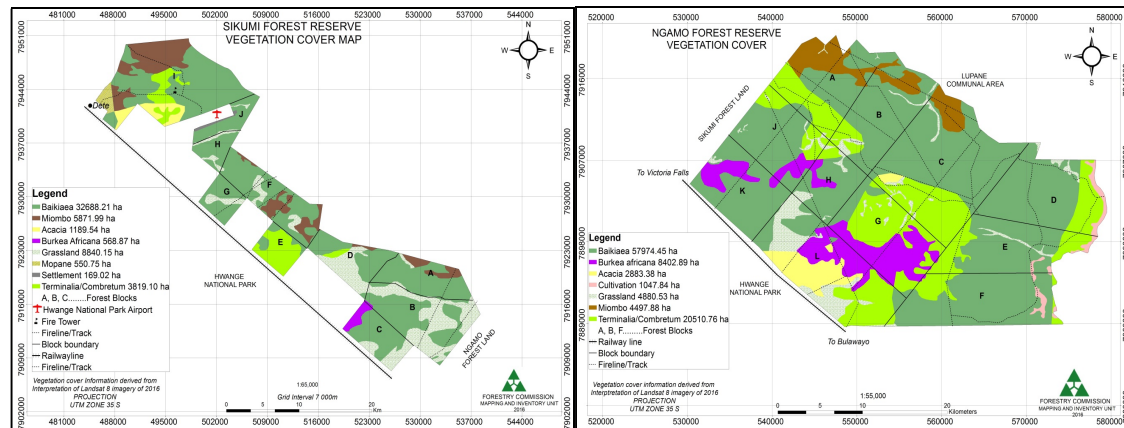
Figure 1: Carbon accounting area vegetation cover maps

Plots will be allocated per vegetation strata and the number of plots per strata will be derived using the formula below:

$$n = \frac{(\sum_{h=1}^{L} N_h \times s_h)^2}{\frac{N^2 \times E^2}{t^2} + (\sum_{h=1}^{L} N_h \times s_h^2)}$$

Where:

E = allowable error or the desired half-width of the confidence interval.

Calculated by multiplying the mean carbon stock by the desired precision (that is, mean carbon stock x 0.1, for 10% precision, or 0.2 for 20% precision),

t = the sample statistic from the t-distribution for the 95% confidence level. t is usually set at 2 as sample size is unknown at this stage,

Nh = number of sampling units for stratum h (= area of stratum in hectares or area of the plot in hectares),

n = number of sampling units in the population

sh = standard deviation of stratum h.

The sampling unit will be a cluster made up of 3 Nested Circular Plots (Fig 2), where the centre of the first point (southern most point) is the determination point for the location of the cluster. This point will be located using the coordinates allotted to the sampling unit on the map and GIS. Each plot will have a radius of 20 metres
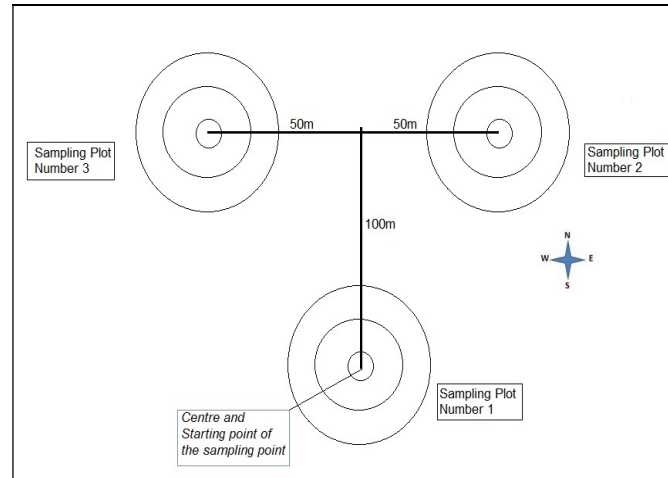
Figure 2: Cluster design

2.1 Cluster Distribution

The distribution of the clusters within each vegetation strata shall be done randomly using GIS software. Each cluster will be made up of 3 plots (Fig 2) e.g a vegetation stratum which has been allocated 15 plots will have 5 clusters. Within the plots the centre will be marked with a small treated wooden pole and 2 trees next to the centre will also be painted.
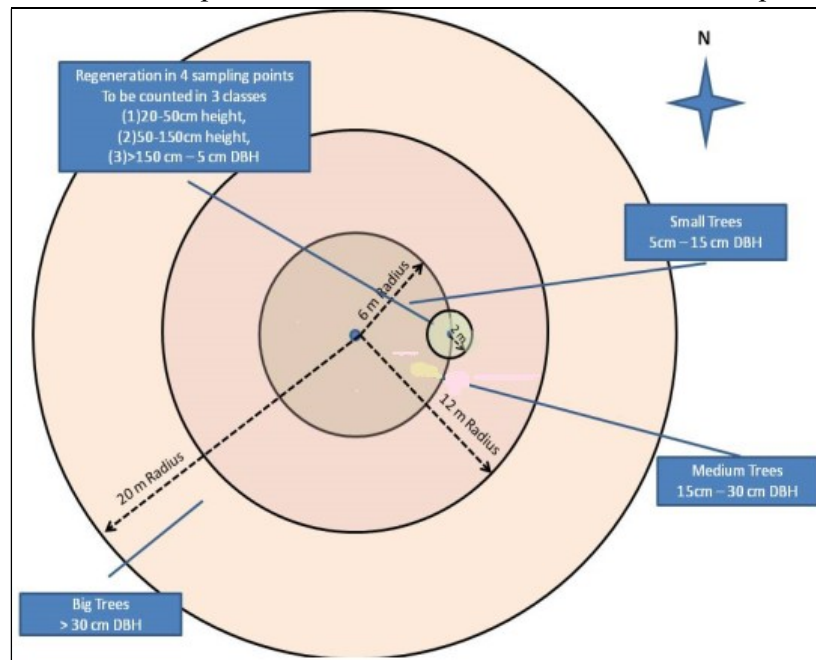
Figure 3: Sampling Plot design
(Nested Circular Plot)

DBH and size	Plot Radius
height 20 cm – 50 cm (Regeneration)	2 m
height 50 cm – 129 cm (Regeneration)	2 m
height 130 cm – DBH 4,9 cm (Regeneration)	2 m
DBH 5 cm – 14.9 cm	6 m
DBH 15 cm – 29.9 cm	12 m
DBH > 30 cm	20 m

2.2 Locating approach of units in the field

The location of the sampling unit is determined by it Coordinates, which will be entered / downloaded on a GPS instrument.

Figure 4: Garmin handheld GPS

2.3 Identification of forest boundary

The forest boundaries of Ngamo and Sikumi will be delineated using features on existing 1:50 000 maps from the Government of Zimbabwe Surveyor General. Additionally the forest boundary is defined by the density (crown coverage 10%) and the height of trees (minimum tree height at maturity in situ of 5m) and a minimum size of 0,5 ha (Food and Agriculture Organisation, 2005).

2.4 Sampling procedure

The following data will be collected per plot:
  i)   General Information
  ii) Natural Regeneration (2m radius)
  iii) Information on trees: DBH 5cm – 14.9 cm(6m radius); DBH 15 cm – 29.9 cm(12m radius); >30cm in diameter (20 m radius)
  iv) Deadwood (6m radius)

2.4.1 General Information

The general information on the sampling unit is filled in on the top of the field record sheet.

Relocation: The first information to be recorded is to indicate if the point centre had to be re-located or is located at the original distance. Then is the direction and distance of the relocation to be noted in case the point is re-located.

Page: The page number and the total of pages filled for this inventory unit point is to be filled.

Sampling unit and sampling point: For identification the sampling unit number has to be filled on all pages of a sampling point. Also the number of the point, which can be only 1 – 3 has to be noted.

REDD+ Forest Inventory Sheet – HSBCP (Ngamo-Sikumi Forests)

Relocation of point: Yes ☐ No ☐	Relocation: Direction:W☐ E☐ N☐ S☐ Distance: m		Area Name:	Page No: of pages
	Date:	Team:		
Sampling Unit No	Sampling Point No	Forest Type	GPS Northing	GPS Easting

Figure 5: General Information Section on the field data sheet

Date and Team: For identification purpose and in case of any questions regarding the point the date of assessment and the team leader name has to be noted.

GPS Records: To make relocation and quality reconfirmation possible the GPS location of each sampling point needs to be recorded. The actual readings of the GPS at the centre of the sampling points need to be recorded.

2.4.2 Tree related measurements

The assessment of trees, including small trees and regeneration is carried out in a full count and assessment of all trees within the respective circular sampling plots. To synchronize required amount of sampling trees and measuring effort, trees of different sizes are assessed in plots with different radius.

2.4.2.1 Natural Regeneration

To avoid disturbance of the regeneration count by the establishment of assessment point centre, the regeneration plot centre is located at 6 m distance to the east (90°) from the assessment point centre. The regeneration of trees, including the important bush and shrub species (as listed in the tree species list) has to be counted per species in 3 height classes in their respective circle. Coppices from coppice trees for are recorded under regeneration, in the respective size class if the coppice sprout centre is within the 2 m circle. All coppices

from one stump are treated as individuals. The Tally field is to be used for tallying during the counting of regeneration; the total is then recorded undercount.

Regeneration Circle (2 m / in 6 m east from centre)								
Small Regeneration 20-50 cm (H)			Medium Regeneration 50-130 cm (H)			Big Regeneration 130 cm – 5 cm DBH		
Species Code	Tally	Count	Species Code	Tally	Count	Species Code	Tally	Count

Figure 6: Regeneration Records

2.3.3 Trees

2.3.3.1 Small trees

Included in the sample are all trees from **5 to 14.9 cm DBH** which are within a distance of 6 m from the centre of the sampling plot. The trees selected and measured should be numbered consequently. The sweep for identification of the sampling trees should always start in North. Trees and sprouts from coppices are treated as individual trees, thus they will be numbered and recorded each with a number, as long as they qualify with their DBH to be located in a respective circle. The numbering starts with the first tree with the sweep starting in north to turn clockwise towards east. Numbering starts for each sampling plot (different radius for different DBH classes) new. The assessment of trees should be done for each plot size separately. The assessed trees should be marked with chalk. The distance to confirm the inclusion in the sample is the distance from plot centre to tree centre. The records are filled into field record sheet following the instructions in the header of the table for small trees regarding the units of measure and the digits to be filled in.

Poles and small trees (5 – 14,9 cm DBH) - 6m radius circle							
Tree No	Species Code	DBH (xxx.x cm)°	Height (xx.x m)	Health/Damage (code)	Decay % dead trees	Distance (xx.xx m)	Bearing (xxx°)

Figure 7: Tree measurements information records

The tree species names are recorded with code, as provided from the tree species attached on this document.

The Diameter at breast height (DBH) has to be taken at a point 1.3 m above the ground. In case of uncertainty for the measuring point, reference should be taken to the illustration below (Figure 8), indicating the appropriate DBH measuring point.
The DBH is measured with a diameter tape or calliper. The diameter recorded from calliper measurements should be the average of two measurements perpendicular to each other. The Diameter is recorded in centimetres.
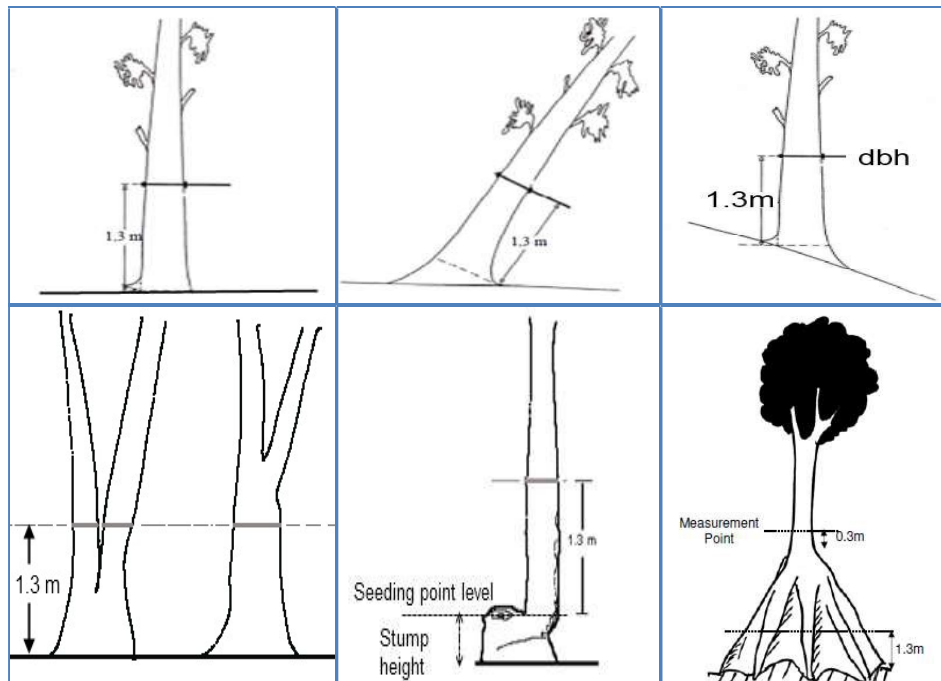
Figure 8: Measuring points for Diameter

The tree height is measured with the clinometer based instrument Haglof Electoronic Clinometer (Haglöf EC II-D). The measurement is based on a distance and angle measurement. The measurement is done with the following steps:

1) Switch on the unit
2) Walk a distance approximately as far as the object's height usually 10m and set the distance by pressing either the +/- button. The set distance flashes in the instrument display
3) Press the On button and the unit moves to degrees. Measure the angle to the base of the tree. The calculated angle flashes in the instrument display. Press the On button again to proceed to height
4) Aim at the height to measure (top of the tree). Long press the On Button until the figure being displayed becomes static. The height is locked and displayed.
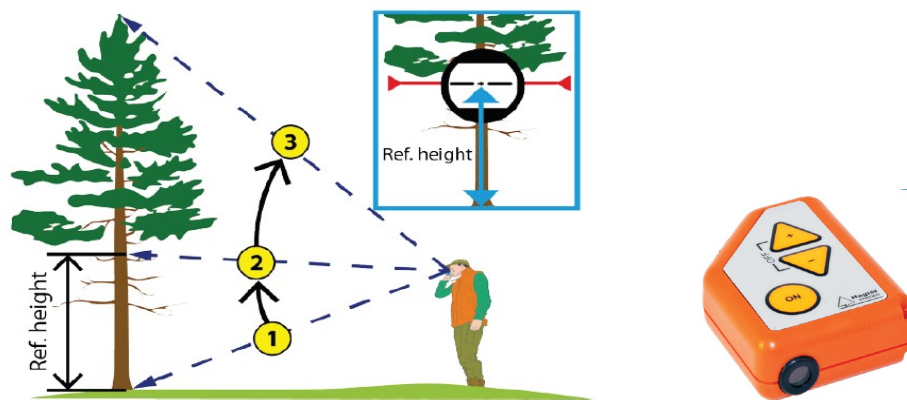
Figure 9: Tree height measurement using the Haglof EC II-D unit (Source: Haglof Electronic Clinometers Product Sheet, 2018)

Bearing and distance from plot centre to the centre of the tree has to be measured and recorded to facilitate control and re-measurement and to document the quality of the assessment (Fig 10). The Bearing is measured with a handheld compass, records are at 1 degree. The Compass should have a 360 degree scale. The distance from plot centre is measured with a measuring tape as horizontal distance. The distance is recorded in meters at accuracy of 2 digits for centimetres.
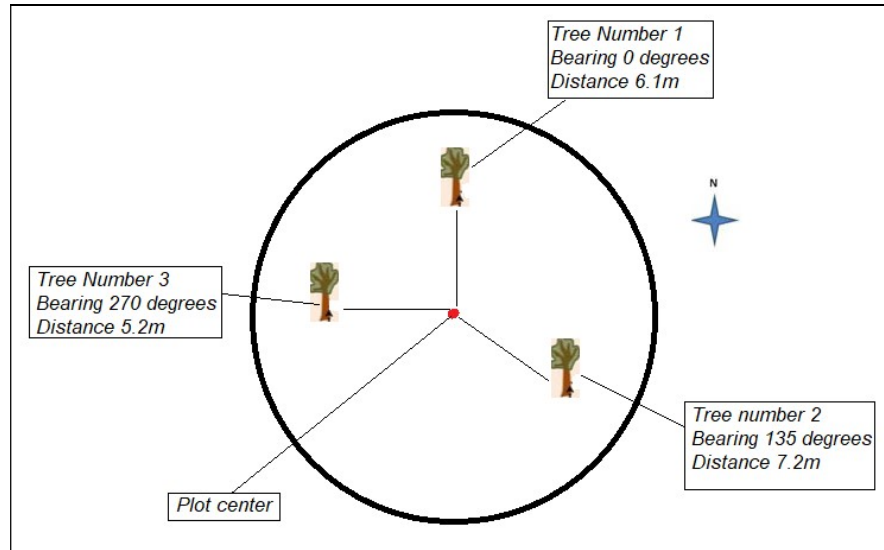
Figure 10: Bearing and distance from plot center

Health and Damage should be assessed by expert's assessment using the damage classification listed in the table below. Besides fire damage; Ngamo and Sikumi Forests are prone to Elephant damage thus it is imperative that elephant damage be listed as one of the health status parameters.

ID	Damage Description	ID	Damage Description
0	No Damage	31	Other Slight
11	Elephant Slight	32	Other Moderate
12	Elephant Moderate	33	Other Severe
13	Elephant Severe	34	Other Extreme
14	Elephant Extreme	45	Standing dead
21	Fire Slight	46	Recently Dead
22	Fire Bole Moderate	47	Unidentified Dead Tree
23	Fire Crown Slight		
24	Fire Extreme		

2.3.3.2 Medium Trees

Included in the sample are all trees from **15 to 29.9 cm DBH** which are within a distance of 12 m from the centre of the sampling plot. The distance to confirm the inclusion in the sample is the distance from plot centre to tree centre. The observations and measurements are the same as described above for the small trees.

Medium trees (15-29.9 cm) - 12 m radius circle							
Tree No	Species Code	DBH (xxx,x cm)	Height (xx,x m)	Health (code)	Decay % dead trees	Distance (xx,xx m)	Bearing (xxx°)

2.3.3.3 Big trees Trees

Included in the sample are all trees **above 30 cm DBH** which are within a distance of 20 m from the centre of the sampling plot. The distance to confirm the inclusion in the sample is the distance from plot centre to tree centre. The observations and measurements are the same as described above for the small trees.

Big trees (>30 cm DBH) - 20 m radius circle							
Tree No	Species Code	DBH (xxx,x cm)	Height (xx,x m)	Health (code)	Decay % dead trees	Distance (xx,xx m)	Bearing (xxx°)

2.3.4 Deadwood

Ngamo and Sikumi have significant amounts of deadwood thus deadwood will be measured within the 6m radius plot. The lying dead wood in the 6 m radius circle will be measured by the mid diameter and the length of the log, as far as it is inside the circle. Dead wood logs that lay across the circle boundary will only be measured that part that is inside the circle (Figure 12). The records for length are in meters to the nearest decimetre (1 digit after the dot, example 3.4 m). The records for mid diameter are rounded to full centimetres. The decay of the log is estimated in percent by expert judgement. The decay percentage describes the loss of biomass and thus carbon compared to a live tree through parts of the log being hollow, moulded or otherwise decayed. The estimation should be given in 5% steps only.

Dead wood - 6 m radius circle							
Log No	Decay %	Mid diameter (xxx,x cm)	Length (xx,x m)	Log No	Decay %	Mid diameter (xxx,x cm)	Length (xx,x m)

Figure 11: Deadwood records
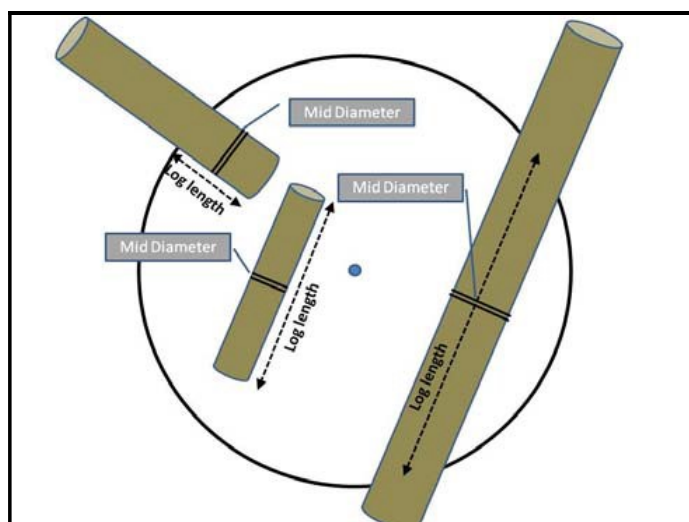
Figure 12: Deadwood measurement

3.0 Quality Assurance and Control

To ensure that data is collected properly the Forest Inventory field team will be trained on the sampling procedure and forest inventory equipment prior to commencement of the biomass assessment field work. Each team will also be led by a trained officer during field data collection. For quality control, 1 cluster will be randomly selected for re measurement.

4.0 Carbon Monitoring

One cluster per vegetation strata will be randomly selected for future measurements to quantify the carbon sequestration/emission. All trees above 5cm dbh within the cluster will be painted and uniquely tagged thus forming Permanent Sample Plots. Carbon monitoring will also involve landcover change detection within the carbon accounting area. This will be done using GIS and remote sensing and the equation below will be used to estimate carbon emmissions:

Basic Equation for GHG Emissions:
GHG Emissions= Activity Data x Emission Factors
e.g (1000 ha) x (90 t C/ha) = (90,000 t C)
*Forest Cover and Cover Change Assessment in terms of area = Activity Data (AD) (Remote Sensing)
*Forest Carbon Stock = Emission Factors (EF)(Terrestrial Inventories)

4.1 Measurement frequency

The Permanent Sample Plots will be measured after every 5 years to quantify the carbon changes.

5.0 Data Capture and analysis

Data will be punched into Microsoft Access data base and Biomass per hectare values will be derived from allometric equations embedded within the data base.

6.0 Field Safety

Necessary measures will be taken to ensure the safety of the field teams. Each team member will be allocated two pairs of poly cotton work suits, a helmet and a pair of safety boots. Each team will be accompanied by an armed member of the Forest Protection Unit to ensure safety from wild animals.

7.0 REFERENCES

Deutsche Gesellschaft fuer Internationale Zusammenarbeit (GIZ); 2013 Development of Integrated Monitoring Systems for REDD+ in the SADC region

Haglof Electronic Clinometers Product Sheet, 2018

8 ACTIVITY DATA ASSESSMENT

The general frame requires, options and guidelines for a RS based assessment of forest cover changes are outlined in the GOFC-GOLD REDD Sourcebook and IPCC Guidelines. The assessment activity data can be viewed in two categories; assessment of changes of forest to other land use (deforestation) and assessment of changes of forest land remaining forest land (forest degradation)

A spatially explicit approach as described by GOFC-GOLD 2012 is applied for assessment activity data. EO-data form basis of this analysis. The monitoring concept will consider the assessment of historical changes for the establishment of the reference level against which performance (reduction in emissions) will be ascertained.

The IPCC recommends a historical period of 20years as a default value and thus it is assumed that the epochs for the historical deforestation assessment for this project will be 1995, 2005 and 2015. This section will describe the main steps that will be implemented to assess the activity data for the various sites. The steps follow those recommended in the GOFC-GOLD Sourcebook (2012) in chapter 2.1 "monitoring of changes in forest area" and chapter 22 "monitoring of change in forest land remaining forest land"

8.1 Step 1; Key definitions: Forest, deforestation, degradation

The definition of forest and the REDD+ eligible activities and degradation are primordial for the setting u of any MRV system. The Marrakech Accord outlined a range of values for the main quantitative parameters in the forest definition with minimum area, minimum crown cover and minimum height (see table 2). Due to technical limitations in EO based monitoring (imposed by the spatial resolution of images which is directly correlated to cost) it is important that a minimum area is chosen which is cost effective to monitor. Whilst countries can have deferent definitions for different purposes, it is preferable to have a common definition for climate change related processes taking into technical specifications of RS data.

Forest: Land spanning more than 0.5 ha with trees higher than 5 meters and canopy cover of more than 10%, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use."

Table 2; Quantitative parameters for forest definition, range of values provided through the UNFCCC Marrakesh Accords and the values for the FAO Forest definition which is used in REDD MRV

Parameters for forest definition	UNFCCC	Regional REDD Forest Definition for Zimbabwe adapted from FAO
Minimum area	0.05-1.0ha	>0.5ha
Minimum crown cover	10-30%	>10%
Minimum tree height at maturity in situ	2-5m	5m

The estimation of deforestation is determined by the definition of forest versus non-forest land. Under Decision 16/CMP.1 the UNFCCC defined deforestation as "… the direct human induced change from forest to non-forested land" Deforestation is driven when the forest cover on an area larger than minimum area of the forest definition decreases below the threshold of the crown cover of the respective forest definition, Temporarily un-stocked areas e.g. through selected logging, with an expected re-growth are not considered as deforestation.in the context of REDD the estimation of degradation is determined by the anthropogenic net emissions from forest in a given time period which is caused by a decrease in canopy cover that does not qualify as deforestation. The IPCC Report "Definition and methodological options to inventory emissions from directed human induced degradation of forests and other vegetation types" (2003) presents five different potential definitions of degradation. However, none of the alternative definitions fully meets the desired characteristics of a definition of forest degradation as follows

"As direct human-induced long-term loss (persisting for X years or more) of at least Y% of forest carbon stocks [and forest values] since time T and not qualifying as deforestation"

It still remains to specify an area threshold if desired, as well as time and carbon loss thresholds in order to operationalize such a definition. In order to distinguish from forest activities the decrease should be considered persistent.

With the lack of a clear definition for degradation it will be difficult to design a purely based EO based monitoring system. Especially in the woodland ecosystems of Zimbabwe the changes in canopy cover will only be apparent in the satellite images when they are not small

and when they produce systematic patterns in the imagery. Therefore, a time series of terrestrial inventories, combined with EO mapping will be the main tool to properly identify and quantify changes in forest cover and related carbon stock with high accuracy. The EO mapping of indicators for degradation will make the terrestrial inventory more efficient by providing strata of intact and non-intact forest and is therefore reducing the sampling error.

8.2 Step 2: Design of forest Area for Acquiring Satellite data

Generally, the REDD+ monitoring needs to cover all forest areas which needs to be monitored for each reporting period. According to GOFC-GOLD Sourcebook 2012 the forest mask is a means to designate the area to be reported on. The satellite data acquired (i.e. Landsat and RapidEye data) for the site has wall-to-wall coverage.

8.3 Step 3: Selection of Satellite imagery and coverage

The selection of the appropriate satellite data for a specific mapping purpose is driven by the components:

- Thematic Discrimination
- Minimum Mapping Unit (MMU)
- Accessibility
- Costs

For the thematic discrimination of forest land from other IPCC compliant land use classes-cropland, grassland, settlement, wetland and others, sensors types with VNIR and SWIR have more stable information stable information content than sensor types with just VNIR which in turn have more stable information content for forest discrimination than SAR. Amongst the available RADAR based systems, the L-band like ALOS PALSAR has demonstrated viable results in mapping forest cover.

The MMU is another crucial criterion for selection of EO data for mapping activity data. The MMU is usually defined by the user but due to the fat that each satellite sensor has a specific spatial resolution this becomes a determining factor in identifying the best suited satellite data that can meet as close as possible the required MMU. The choice of satellite data is directly correlated to cost; e.g. generally the finer the resolution the more expensive the data. GOFC GOLD 2011 recommends a MMU of 1-6 ha for mapping activity data.

Accessibility of EO relates to aspects like the availability of datasets in archives, data access conditions and reliability, repetitive rate and influence on new acquisitions. Additionally, the MRV system should initially consider cost free optical data. Therefore, Landsat TM and ETM (cost free optical data) will constitute the basis of data for the periods (1995 and 2018) as Landsat has the most exhaustive archive of historical satellite data. Presently, SPOT and RapidEye (commercial) are the only operational optical high resolution data available. In case of the pilot project in the test areas RapidEye data with resolution of 6.5m will form the basis for 2015 epoch. To ensure the deciduous forests are properly detected and classified, dual coverages of rapid eye data will be ordered.

Future monitoring will consider the sentinel 2, Landsat continuity mission, ALOS 2 and other missions currently in development. It is important that the established MRV systems ensure compatibility with the EO missions currently being developed.

Step 4; Decisions for sampling versus wall-to-wall coverage

There are basically two approaches for assessing activity data; wall to wall mapping and sampling approach. The wall to wall approach even though more exhaustive and expensive has the advantage of spatially explicit detection of changes for entire project area thereby facilitating the understanding of drivers of change. Moreover the wall to wall maps can be employed for other applications.

Step 5; Process and analyse satellite data

Specification of mapping products based on user requirements

As noted in the GOFC GOLD 2012 "…the estimate of reductions in emissions from deforestation and degradation requires assessing reference emissions levels against which future emissions can be compared. These reference levels represent the historical emissions from deforestation and degradation in forested land" Thus the baseline assessment will require the assessment of the DD rates over a specific period of time. These assessments will be based on the classification of multi-temporal and multi-spectral satellite data and will result in series of mapping products.

The mapping products in the HSBCP REDD MRV system are at set of Thematic Maps with varying thematic contents. The main thematic map products of the services will be Forest

cover and forest cover change maps classified into IPCC compliant Land use classes to provide reliable information of DD. The production of the forest/non forest maps is based on high resolution satellite data and will be conducted for a historic period. Degraded forest areas will be assessed by the production of forest degradation maps. The degradation mapping will include intact and non-intact forest categories. This assessment will be made between a minimum of two epochs as degradation is inherently a process occurring over time. The following sections provide detailed specifications for these products. According to the ISO standard EN ISO 19131; 2008/A1.2011: *"a data product specification is a detailed description of a data set or dataset series together with additional information that will enable it to be created, supplied to and used by another party. It is a precise technical description of the data product in terms of the requirements that it will or may fulfil. However the data product specification only defines how the dataset should be. For various reasons, compromises may need to be made in the implementation. The metadata associated with the product dataset should reflect how the product dataset actually is*" In this context the product specifications in the REDD MRV project in this section will be applied.

Product Specifications of forest cover map

The forest cover map described in the following table is an annual forest layer snapshot of forest and non-forest extents. It serves as a baseline for national evaluations of forest resources. The forest cover map contains the classes forest and non-forest area. The following table provides the detailed specifications of this product.

Table 3: Product Specification of Forest Cover Map

Title: Forest Cover Map	
Abstract	Forest Cover maps showing Forest vs. Non-forest. Forest definitions adhere to National or International standards (e.g, FAO, IPCC 2006), or specific national and regional forest definition. Forest classification is obtained from EO data from different sources using image classification techniques.
Service/Product Specifications	
Service Area/ Geographical Scale	General options: A)Wall-to-wall: Project area (Ngamo and Sikumi Forests HSBC REDD MRV Project: Biome Approach based on Ecosystems, prototyping in the test areas (sub-national) of approximately 160000Ha representing one of the most widespread Ecosystems. 1. Baikiea Woodlands: Zimbabwe

Mapping Classes and Definitions	Forest
	Non-forest
	(Definitions according to national/regional user requirements or as recommended in the COP16 Decisions which reference definitions related to Marrakesh Accord 2001. In the absence of a national/ regional forest definitions, GOFC-GOLD 2012 recommends FAO definition)
	
	HSBC REDD MRV Project:
	Zimbabwe: FAO definition with the parameters:
	   1. Minimum area <0.5ha
	   2. Minimum crown cover >10%
	   3. Minimum tree height at maturity age.>5m

Time Period- Update Frequency	Assessment of historic, current and future periods (e.g. global historic EO data sets are freely available for the years 1975, 1990, 2000, 2005, 2010 etc). Future update frequency: possible on at least annual basis Historic: user defined or 20 years interval as recommended in GOFC-GOLD 2012 HSBCP REDD MRV Project: 2000 and 2018 as the time period to be monitored in the project area
Geographic Reference System	Generally possible in any National System would require user inputs at the very beginning of the production process in terms of providing projection parameters and reference data sets, like ortho-photo maps, Digital Elevation Models, etc. In absence of national systems the UTM, WGS 84 can be used which is a wide spread reference system applied in many global mappings.
Spatial Representation	Can be provided in Thematic Raster or Vector HSBCP MRV Project:
Spatial Resolution	Output pixel size ranging from 5 to 30m dependent on EO input data and user requirement (RapidEye: 5m, Landsat TM: 30m) HSBC REDD MRV Project: The Pilot Project is making use of historic Landsat data with 30 spatial resolution and RapidEye data with 6.5m resolution for the current coverages
Minimum Mapping unit	The UNFCCC- through the Marrakesh Accords- requests the countries to develop a forest definition for REDD+ with a minimum forest area within the ranges of 0.05ha and 1.0ha. In order to minimize the uncertainty of forest mapping it is recommended to define the Minimum Mapping Unit in accordance with the minimum forest area of the forest definition. HSBC REDD MRV Project: The specified MMU of 0.5 ha which is compliant with the 0.5 ha minimum forest area of the applied FAO forest definition shall be used.
Format	General options: .img and shp. (All standard raster data formats available (e.g. GEOTIFF, .img,), original 8 bits per pixel, and standard vector formats (e.g., .shp, .dxf, geodatabase).)

	HSBC REDD MRV Project:
Metadata	HSBC REDD MRV Project: ISO TC 211 compliant to ISO19115:2003 Metadata

Service/Product Quality	
Quality Assurance	All quality relevant information and quality checks are documented and cover the categories: • Compliancy of output with IPCC and user requirements • Completeness • Thematic accuracy • Thematic completeness • Positional Accuracy Quality Management Systems are applied to cover non-conformance issues, timely corrective action, and customer services related to reliability, flexibility and timely delivery of services HSBC REDD MRV Project: IPCC2006 Vol. 1, Chapter 6 compliant
Thematic Accuracy	The service provides evidence on Thematic Accuracy, defined on the basis of documented procedures with defined sampling scheme, size , unit, criteria, reference data and evaluation process Accuracy is the agreement between the true value and repeated measured observations or estimations of quantity (GOFC-GOLD, 2012). The thematic accuracy figures are presented in confusion matrices, presenting the overall class accuracy, as well as user and producer accuracies for each class. The observations of the true values are usually done with higher resolution data, such as Ikonos, Worldview, GeoEye, Plaides, etc The feasibility accuracies with current sensors range between 75% to 90% ±5% HSBC REDD MRV Project: The HSBC requires: "a gross error less than 5% is to be aimed for determination of Forests"
Positional Accuracy	Geometric accuracy is dependent on the geometric resolution of the input EO data; it will be defined from check points and visual overlay with reference data. Presented as RMS error. With current sensors feasible RMS errors ranges from 0.5 to 2.5 pixels.

Input data	
Earth Observation (EO) data	Several input data options exists Optical data • >=30m: Landsat-4/5 TM, Landsat -7 ETM+ • >=10m/20m: IRS-P6 LISS-III, IRS 1C/D ms, Spot 2/4/5 (Sentinel 2 from 2014 onwards) • >=5m: RapidEye, PAN: Spot, IRS Alternatives: Deimos, DMC, ALOS AVNIR, ASTER

	SAR data: ERS SAR data (since 1991), ALOS PALSAR data (2007 to 2010) Alternatives: JERS SAR, Radarsat 2, Cosmo-SkyMed, TerraSAR
Spectral Bands	Optical: Red/NIR/SWIR recommended, RedEdge also acceptable SAR: L-Band recommended, C-, X-Band acceptable
Reference Geographic Data	Available options to improve geometric referencing: Digital Elevation Model; e.g. SRTM 90m with a specified resolution (positional and vertical) GLS 1990, 2000 and 2005, other EO data sets (satellite or airborne data) with sufficient resolution as geometrical data basis. Topographic data or other data source providing geo-reference of objects visible on the images HSBC REDD MRV Project: Department of Surveying and Mapping in Zimbabwe has various reference data sets such as Topographic, Cadastral and Orthophotos available at various scales and in digital format, which can be procured for the project.
Auxiliary Data	Available options for improving thematic classification In-situ data Forest data Aerial photos, VHR data, etc HSBC REDD MRV Project: Department of Surveying and Mapping in Zimbabwe has various reference data sets such as Topographic, Cadastral and Orthophotos available at various scales and in digital format, which can be procured for the project.
Processing	
Pre-processing	Geometric correction of EO data based on geographic reference data available DEM
Thematic Processing	Classification procedure describes all steps of automated and manuals steps carried out to produce the thematic map with the specified forest type classes. General steps: Classification: segment and/or pixel based Classification refinement (manual improvement, filtering steps) Quality control of classification
Post-Processing	Output production (digital and/or printed): Digital coding of classes User agreed map layout (specific map legend, colour codes, map elements)
Accuracy Assessment	Stratified random sampling based on area frames and/or point samples
Customer Service	
Service Interface	User is responsible for the service activation Service Provider is responsible for EO data acquisition and data provision
Service Provision	Online download service via WMS, FTP Offline service via hard disk, DVD
Service Delivery	In time period agreed with user

Conditions Applying to Access and Use	Access restricted to user (can be extended on request by the user)
Archive	Data storage possible
Customer Care	• Customer care support team available • User Feedback service available

Product Specifications of Forest Cover Change Map

The Forest Cover Change Map has to be compliant with the IPCC land use categories: forest land, cropland, settlement, grassland, wetland and other land. The following table describes the detailed specifications of the Forest Cover Change Map product.

Table 4: Specifications of Forest Cover Change Map (classified into IPPC compliant Land Use classes)

Title: Forest Cover Change Map (classified into IPCC compliant Land Use classes	
Abstract	Forest cover maps showing vs Non- forest, optionally, other wooded lands. Non forest class can be subdivided into several broad land use classes. Forest definitions adhere to International standards (e.g., FAO, IPCC 2006). Forest classification is obtained from EO data from different source using image classification techniques. Forest Cover Change Map can be used to derive deforestation rates to support reporting obligations to national/international convections (e.g. REDD), decision making within sustainable environmental monitoring practices, and/or as input to forest management tools and GIS for further analysis.
Service/Product Specifications	
Service Area	General options: A)Wall-to-wall: Regional, National, Sub-national HSBC REDD MRV Project: Regional Approach based on Ecosystems, prototyping in the test areas (sub-national) of approximately 160 000Ha each representing one of the most widespread Ecosystems. Agreed Ecosystems in the project area: 1. Baikiea Woodlands: Zimbabwe
Mapping classes and definitions	Forest remaining Forest Changes to/from forest from/to the following categories: Cropland: this category includes arable and tillage land, and agro-forestry systems where vegetation falls below the threshold use for forest land category, consistence with the selection of national definitions Grassland: This category includes rangelands and pasture land that is not considered as cropland. It also includes systems with vegetation that fall below the threshold

used in the forest land category and is not expected to exceed, without human intervention, the threshold used in the forest land category. The category also includes all grassland from wild lands to recreational areas as well as agricultural and silvi-pastural systems, subdivided into managed and unmanaged consistent with national definitions.

Wetlands: this category includes land that is covered or saturated by water for all or part of the year (e.g., peatland) and that does not fall into the forest land, cropland, grassland or settlement categories. The category can be subdivided into managed or unmanaged according to national definitions. It includes reservoirs as a managed sub-division and natural rivers and lakes as unmanaged sub-divisions.

Settlements: This category includes all developed land, including transportation infrastructure and human settlement of any size, unless they are already included under other categories. This should be consistent with the selection of national definitions.

Other land: This category includes bare soil, rock, ice and all unmanaged land areas that do not fall into any of the other five categories. It allows the total of identified land areas to match the national area, where data are available.

(definitions according to or compliant with IPPC GPG)

Time Period-Update Frequency	Assessment of historic, current and future periods (e.g. global historic EO data sets are freely available for the years 1975, 1999, 2000, 2005, 2010*). Future update frequency: possible on at least annual basis Historic: user defined or 20 years interval as recommended in GOFC-GOLD 2012 HSBC REDD MRV Project: 2000 and 2017 as the time period to be monitored in the project area *only limited utility due to failure of the Landsat 7 system
Geographic Reference System	Generally possible in any National System would require user inputs at the very beginning of the production process in terms of providing projection parameters and reference data sets, like ortho-photo maps, Digital Elevation Models, etc. In absence of national systems the UTM, WGS 84 can be used which is a wide spread reference system applied in many global mappings.
Spatial Representation	Generally: can be provided in Thematic Raster or Vector HSBC REDD MRV Project:
Spatial resolution	Output pixel size ranging from 5 to 30m dependent on EO input data and user requirement (RapidEye: 5m, Landsat TM: 30m) HSBC REDD MRV Project: The Project is making use of historic Landsat data with 30 spatial resolution and RapidEye data with 6.5m resolution for the current coverages
Minimum Mapping Unit	The UNFCCC- through the Marrakesh Accords- requests the countries to develop a forest definition for REDD+ with a minimum forest area within the ranges of 0.05ha and 1.0ha. In order to minimize the uncertainty of forest mapping it is recommended

	to define the Minimum Mapping Unit in accordance with the minimum forest area of the forest definition. HSBC REDD MRV Project: The HSBC specifies a MMU of 0.5 ha which is compliant with the 0.5 ha minimum forest area of the applied FAO forest definition.
Format	General options: .img and shp. (All standard raster data formats available (e.g. GEOTIFF, .img,), original 8 bits per pixel, and standard vector formats (e.g., .shp, .dxf, geodatabase).)
Metadata	HSBC REDD MRV Project: ISO TC 211 compliant to ISO19115:2003 Metadata
Service/Product quality	

Quality Assurance	All quality relevant information and quality checks are documented and cover the categories:
	    • Compliancy of output with IPCC and user requirements
	    • Completeness
	    • Thematic accuracy
	    • Thematic completeness
	    • Positional Accuracy
	Quality Management Systems are applied to cover non-conformance issues, timely corrective action, and customer services related to reliability, flexibility and timely delivery of services
	
	HSBCREDD MRV Project:
	IPCC2006 Vol. 1, Chapter 6 compliant

Thematic Accuracy	The service provides evidence on Thematic Accuracy, defined on the basis of documented procedures with defined sampling scheme, size , unit, criteria, reference data and evaluation process Accuracy is the agreement between the true value and repeated measured observations or estimations of quantity (GOFC-GOLD, 2012). The thematic accuracy figures are presented in confusion matrices, presenting the overall class accuracy, as well as user and producer accuracies for each class. The observations of the true values are usually done with higher resolution data, such as Ikonos, Worldview, GeoEye, Plaides, etc The feasibility accuracies with current sensors range between 75% to 90% ±5% HSBC REDD MRV Project: The project requires: "a gross error less than 5% is to be aimed for the determination of Forests," No strict requirement for the accuracy of the other landuse are defined.
Positional Accuracy	Geometric accuracy is dependent on the geometric resolution of the input EO data; it will be defined from check points and visual overlay with reference data. Presented as RMS error. With current sensors feasible RMS errors ranges from 0.5 to 2.5 pixels.

Input data	

Earth Observation (EO) data	Several input data options exists:
	
	• Optical data:
	    o >=30m: Landsat-4/5 TM, Landsat -7 ETM+
	    o >=10m/20m: IRS-P6 LISS-III, IRS 1C/D ms, SPOT 2/4/5 (Sentinel 2 from 2013/14 onwards)
	    o >=5m: RapidEye, PAN: SPOT, IRS
	Alternatives: Deimos, DMC, ALOS AVNIR-2, ASTER
	
	• SAR data:
	    o ERS SAR data (since 1991), ALOS PALSAR data (2007 to 2010)
	
	Alternatives: JERS SAR, Radarsat 2, Cosmo-SkyMed, TerraSAR

Spectral Bands	Optical: Red/NIR/SWIR recommended, RedEdge also acceptable SAR: L-Band recommended, C-, X-Band acceptable
Reference Geographic Data	Available options to improve geometric referencing: Digital Elevation Model; e.g. SRTM 90m with a specified resolution (positional and vertical) GLS 1990, 2000 and 2005, other EO data sets (satellite or airborne data) with sufficient resolution as geometrical data basis. Topographic data or other data source providing geo-reference of objects visible on the images HSBCREDD MRV Project: Department of Surveying and Mapping in Zimbabwe has various reference data sets such as Topographic, Cadastral and Orthophotos available at various scales and in digital format, which can be procured for the project.
Auxiliary Data	Available options for improving thematic classification In-situ data Forest data Aerial photos, VHR data, etc HSBCREDD MRV Project: Department of Surveying and Mapping in Zimbabwe has various reference data sets such as Topographic, Cadastral and Orthophotos available at various scales and in digital format, which can be procured for the project.
Processing	
Pre-processing	Geometric correction of EO data based on geographic reference data available DEM
Thematic Processing	Classification procedure describes all steps of automated and manuals steps carried out to produce the thematic map with the specified forest type classes. General steps: Classification of changes: segment and/or pixel based Classification refinement (manual improvement, filtering steps) Quality control of classification
Post-Processing	Output production (digital and/or printed): Digital coding of classes

	User agreed map layout (specific map legend, colour codes, map elements)
Accuracy Assessment	Stratified random sampling based on area frames and/or point samples
Customer Service	
Service Interface	User is responsible for the service activation Service Provider is responsible for EO data acquisition and data provision
Service Provision	Online download service via WMS, FTP Offline service via hard disk, DVD
Service Delivery	In time period agreed with user
Conditions Applying to Access and Use	Access restricted to user (can be extended on request by the user)
Archive	Data storage possible
Customer Care	• Customer care support team available • User Feedback service available

Product Specification of Degradation Map

The Degradation Map will be produced following IPCC GPG and GOFC-GOLD Source Book. The approach is likely to focus on the identification of intact and non-intact forest based HR data using the indirect approach described in GOFC-GOLD, 2012. The following table describes the detailed specifications of the Forest Degradation Map product

Table 5: Specification of Forest Degradation Map

Title: Forest Degradation Map	
Abstract	Degraded forest areas are derived from remotely sensed data using the direct or indirect approach described in GOFC-GOLD, 2012. Both methods allow to distinguish intact forest and non-intact forest which include logged forest (recent and older logged forest in the field) degraded forest (heavily burned, heavily logged and burned forest in the field); and regeneration (old heavily logged and old heavily (and burned forests in the field) Since the focus is on estimating forest carbon losses associated with degradation, forest canopy gaps and small clearings are the feature of interest (in case of logging, the damage associated with tree felling: gaps, trails, logging decks), GOFC-GOLD 2012. Activities related to selective logging remain the principal cause of forest degradation just as important as deforestation in the UNFCCC REDD mechanism, consequently forest degradation maps distinguished different degree of degradation will support monitoring and reporting in the REDD framework.
Service/Product Specifications	
Service Area/Geographical Scale	General options: A)Wall-to-wall: Regional, National, Sub-national HSBC REDD MRV Project: Regional Approach based on Ecosystems, prototyping in the test areas (sub-national) of approximately 160 000Ha each representing one of the most widespread Ecosystems. Agreed Ecosystems: 1. Baikieae Woodlands: Zimbabwe
Mapping Classes and Definitions	Intact Forest Non-Intact Forest which include forest canopy gaps, log landings and logging roads Degradation can only be ascertained through assessment over a period of time, i.e. intact forest areas will not change over a period of time whereas degraded areas will change indicating they have just been degraded (significant loss of carbon) or through regeneration (recovery resulting in carbon sequestration) both exhibiting distinct spectral characteristics
Time Period-Update	Assessment of current trends

Frequency	Future update frequency: possible on at least annual basis Historic: user defined or 20 years interval as recommended in GOFC-GOLD 2012
Geographic Reference System	Generally possible in any National System would require user inputs at the very beginning of the production process in terms of providing projection parameters and reference data sets, like ortho-photo maps, Digital Elevation Models, etc. In absence of national systems the UTM, WGS 84 can be used which is a wide spread reference system applied in many global mappings.
Spatial Representation	Generally: can be provided in Thematic Raster or Vector HSBCMRV Project: The GIZ ToR specifies raster data
Spatial Resolution	Output pixel size ranging from 5 to 30m dependent on EO input data and user requirement (RapidEye: 5m, Landsat TM: 30m) HSBCREDD MRV Project: The Pilot Project is making use of historic Landsat data with 30 spatial resolution and RapidEye data with 6.5m resolution for the current coverages.
Minimum Mapping unit	The UNFCCC- through the Marrakesh Accords- requests the countries to develop a forest definition for REDD+ with a minimum forest area within the ranges of 0.05ha and 1.0ha. In order to minimize the uncertainty of forest mapping it is recommended to define the Minimum Mapping Unit in accordance with the minimum forest area of the forest definition. HSBC REDD MRV Project: The HSBC specifies a MMU of 0.5 ha which is compliant with the 0.5 ha minimum forest area of the applied FAO forest definition.
Format	General options: .img and shp. (All standard raster data formats available (e.g. GEOTIFF, .img,), original 8 bits per pixel, and standard vector formats (e.g., .shp, .dxf, geodatabase).) HSBC REDD MRV Project: Zimbabwe: Most Government Departments use ArcInfo sw and therefore all relevant formats for this sw should be used to facilitate data exchange. DFRR specifically requested .shp files.
Metadata	HSBCREDD MRV Project: ISO TC 211 compliant to ISO19115:2003 Metadata
Service/Product quality	
Quality Assurance	All quality relevant information and quality checks are documented and cover the categories: • Compliancy of output with IPCC and user requirements • Completeness • Thematic accuracy • Thematic completeness • Positional Accuracy

	Quality Management Systems are applied to cover non-conformance issues, timely corrective action, and customer services related to reliability, flexibility and timely delivery of services HSBC REDD MRV Project: IPCC2006 Vol. 1, Chapter 6 compliant
Thematic Accuracy	The service provides evidence on Thematic Accuracy, defined on the basis of documented procedures with defined sampling scheme, size , unit, criteria, reference data and evaluation process Accuracy is the agreement between the true value and repeated measured observations or estimations of quantity (GOFC-GOLD, 2012). The thematic accuracy figures are presented in confusion matrices, presenting the overall class accuracy, as well as user and producer accuracies for each class. The observations of the true values are usually done with higher resolution data, such as Ikonos, Worldview, GeoEye, Plaides, etc The feasibility accuracies with current sensors range between 75% to 90% ±5% HSBC REDD MRV Project: The HSBC requires: "a gross error less than 5% is to be aimed for the determination of Forests," No strict requirement for the accuracy of the other landuse are defined.
Positional Accuracy	Geometric accuracy is dependent on the geometric resolution of the input EO data; it will be defined from check points and visual overlay with reference data. Presented as RMS error. With current sensors feasible RMS errors ranges from 0.5 to 2.5 pixels.
Input data	

Earth Observation (EO) data	Several input data options exists:
	
	- Optical data:
	  - >=30m: Landsat-4/5 TM, Landsat -7 ETM+
	  - >=10m/20m: IRS-P6 LISS-III, IRS 1C/D ms, SPOT 2/4/5 (Sentinel 2 from 2013/14 onwards)
	  - >=5m: RapidEye, PAN: SPOT, IRS
	Alternatives: Deimos, DMC, ALOS AVNIR-2, ASTER
	
	- SAR data:
	  - ERS SAR data (since 1991), ALOS PALSAR data (2007 to 2010)
	
	Alternatives: JERS SAR, Radarsat 2, Cosmo-SkyMed, TerraSAR

Spectral Bands	Optical: Red/NIR/SWIR recommended, RedEdge also acceptable SAR: L-Band recommended, C-, X-Band acceptable
Reference Geographic Data	Available options to improve geometric referencing: Digital Elevation Model; e.g. SRTM 90m with a specified resolution (positional and vertical) GLS 1990, 2000 and 2005, other EO data sets (satellite or airborne data)

	with sufficient resolution as geometrical data basis. Topographic data or other data source providing geo-reference of objects visible on the images HSBC REDD MRV Project: Department of Surveying and Mapping in Zimbabwe has various reference data sets such as Topographic, Cadastral and Orthophotos available at various scales and in digital format, which can be procured for the project.
Auxiliary Data	Available options for improving thematic classification In-situ data Forest data Aerial photos, VHR data, etc HSBCREDD MRV Project: Department of Surveying and Mapping in Zimbabwe has various reference data sets such as Topographic, Cadastral and Orthophotos available at various scales and in digital format, which can be procured for the project.
Spectral Bands	Optical: Red/NIR/SWIR recommended, RedEdge also acceptable SAR: L-Band recommended, C-, X-Band acceptable
Reference Geographic Data	Available options to improve geometric referencing: Digital Elevation Model; e.g. SRTM 90m with a specified resolution (positional and vertical) GLS 1990, 2000 and 2010, other EO data sets (satellite or airborne data) with sufficient resolution as geometrical data basis. Topographic data or other data source providing geo-reference of objects visible on the images HSBCREDD MRV Project: Department of Surveying and Mapping in Zimbabwe has various reference data sets such as Topographic, Cadastral and Orthophotos available at various scales and in digital format, which can be procured for the project.
Auxiliary Data	Available options for improving thematic classification • In-situ data • Forest data • Aerial photos, VHR data, etc HSBCREDD MRV Project: Department of Surveying and Mapping in Zimbabwe has various reference data sets such as Topographic, Cadastral and Orthophotos available at various scales and in digital format, which can be procured for the project.
Processing	
Pre-processing	Geometric correction of EO data based on geographic reference data and available DEM
Thematic Processing	Degradation will be assessed on tree cover either through the so-called direct approach as defined by GOFC-GOLD (2009). This approach will be based on the estimation of tree canopy gaps identified on VHR imagery and combined with HR data to linear model of canopy gaps. Other methods include Spectral Mixture

	Analysis (SMA), but these have yet to be fully tested in the Congo Basin region. In addition, the indirect approach can be developed. This involves the identification of intact forest based o the number of criteria as described in GOFC-GOLD, 2012 which needs to be tailored to local conditions. The approach can be applied on its own or combined with the direct approach by providing an initial stratification step.
Post –Processing	Output production (digital and/or printed): • Digital coding of classes • User agreed map layout (specific map legend, colour codes, map elements)
Accuracy Assessment	Stratified random sampling based on area frames and/or point samples
Customer Service	
Service Interface	User is responsible for the service activation Service Provider is responsible for EO data acquisition and data provision
Service Provision	Online download service via WMS, FTP Offline service via hard disk, DVD
Service Delivery	In time period agreed with user
Conditions Applying to Access and Use	Access restricted to user (can be extended on request by the user)
Archive	Data storage possible
Customer Care	• Customer care support team available • User Feedback service available

Relevant Standard to be Applied for Geo-data Handling and processing

Forestry Commission Mapping & Inventory Unit has established a Quality Management System based on ISO 9001: 2008 (QMS) which will be applied for the processing of the mapping products. It requires providing detailed information on data quality elements that are essential to clearly describe the quality of a single data set in a comprehensive, traceable ad standardised manner. This Data Quality information shall be documented in dedicated Data Quality Sheets, which will be delivered together with the thematic data to the client/ user in each case. The final product will be presented by specifying the data content, structure, quality, the reference systems, the metadata and the delivery format and medium as shown generically in the previous tables.

Together with the thematic products and the documentation of the product quality, also dedicated metadata will be provided as an XML file, compliant to the ISO standard 19115 "Metadata"42 and ISO 19139 "XML Scheme Implementation ". According to ISO standard 19115, the core metadata elements required for describing the dataset comprise a title, reference date, and topic category, an abstract describing the dataset, the used dataset language, a point of contact responsible for the metadata and the metadata date stamp as mandatory elements as well as 15 other optional and conditional elements.

Processing Methodology

The processing chains for the Forest Cover, Deforestation and Degradation map products comprise of 4 main components:

- Pre-processing of reference data including field campaigns
- Pre-processing of EO data
- Thematic Processing (e.g. classification)
- Post-processing

The Global Land Survey (GLS) collection of Landsat imagery will be used as geometric reference (30m geodetic accuracy, based on Draft GLS Product Requirements from 2007)

The **Pre-Processing** of EO data comprise of:

- Data Input
  - Data search and acquisition process
  - Quality check and verification of all available Input data (e.g. satellite data, field data)
- Geometric and radiometric processing of satellite data
  - Re-projection (if necessary), resampling and co-registration to a specific raster
  - Quantitative estimation of geometric deviations between Landsat 1990 and 2000 as well as RapidEye data from 2018 and the GLS (or other) reference data set
  - Co-registration of all datasets based on GLS reference data
  - Topographic normalisation (only in rugged terrain, if necessary)
  - Calibration: radiometric adjustment of satellite scenes filtering (Multi-temporal and spatial, if necessary)

The **Thematic Processing** is mainly based on EO data classification procedure. However, processing steps may be different depending on the products in question.

Forest Cover and Forest Cover Change Maps

A multi-spectral classification approach will be used to classify forest and non-forest for the respective epochs (2000 and 2018) and simultaneously determine the changes for the periods 2000-2010 and 2010-2018. In a subsequent step, the changed areas will then be classified into the IPCC compliant land use classes' cropland, grassland, wetland, settlement and other land use. The entire processing steps are summarized as follows:

- Multi-image segmentation (all three epochs) incl. visual comparison of segmentation results to check the quality of the derived segments
- Cloud and cloud shadow masking (all three epochs)
- Field survey for ground truthing
- Semi-automatic classification of Forest and Non- Forest cover based on RapidEye data from 2018
- Manual and interactive post-processing of the derived forest and non-forest cover maps

- Classification of changes between 2010/11 and 2000 as well as 1990
- Detected change areas (e.g. forest 1990/2000 into non-forest 2010/11) will be further classified into the IPCC compliant classes cropland, grassland, wetland, settlement or other land use
- Post-processing to derive the required MMU of0.5ha
- Accuracy assessment (stratified random point sampling) of forest cover maps and detected change areas based on VHR EO data
- Quality assurance and quality documentation

Field missions will be organised to procure ground truth data which will be used to train the algorithms for classification and subsequent validation of the classification products. The complement the ground truth data for accuracy assessment Sentinel data will be acquired.

Step 6: Accuracy Assessment

The accuracy of activity data has a major impact on the overall uncertainty of emission reduction estimates. Therefore, this section presents an approach for the accuracy assessment of the mapped products for the MRV system.

For the implementation of robust accuracy assessment methods three primary components need to be defined as described in GOFC GOLD 2012: **the sampling design,** determines the spatial location of the reference data, **the response design** describes how the reference data is obtained and an **analysis design** defines the accuracy estimates. "Best Practices" for these steps are provided by Strahler et al. (2006). In the framework of the GMES Service Element Forest Monitoring (GSE FM) methods for accuracy assessment have been comprehensively tested and implemented from 2003 to 2012. The following concept is adopted from the GSE FM portfolio.

Sampling Design

The sampling design specifies the sample size, sample locations and the reference assessment units (i.e. pixels or image blocks). Different sampling schemes can be used in collecting accuracy assessment data including: simple random sampling, systematic sampling, stratified random sampling, cluster sampling and stratified systematic unaligned sampling. Randomness provides suitable statistical properties that are important for further analysis of

the results. Systematic and cluster sampling can provide practical advantages. In most cases, stratified sampling is most appropriate

Stratification should be applied in case of rare classes (i.e. for change categories) and to reflect and account for relevant gradients (i.e. Ecoregions) or known factors influencing the accuracy of the mapping process. Stratification can be based on:

- Map classes to be verified
- Independent data sets

Non-probability sampling is any sampling method where some elements of the population have *no* chance of selection or where the probability of selection cannot be accurately determined. It involves the selection of elements based on assumptions regarding the population of interest, which forms the criteria for selection. Hence, because the selection of elements is non-random, non-probability sampling does not allow the estimation of sampling errors. These conditions give rise to exclusion of bias, placing limits on how much information a sample can provide about the population. Information about the relationship between sample and population is limited, making it difficult to extrapolate from the sample to the population.

Probability sampling (required for a sound sampling design) requires that every unit in the population has a chance (greater than zero) of being selected in the sample, and this probability can be accurately determined. The combination of these two constraints makes it possible to produce unbiased estimates of population totals, by weighting sampled units according to their probability of selection.

Therefore, a sampling method is proposed that keeps accuracy and efficiency/ effort in balance and is based on the given situation concerning the availability of reference data. The most cost efficient source of reference data for this HSBCP REDD Pilot is Very High Resolution (VHR) EO data such as from Rapid eye (see Response design Section). Based on the given situation concerning the reference data the following sampling design is suggested, adopting a method described by Stehman et al. (2003).

In this context a two-stage sampling design can be applied, where in the first stage a sample of images which are considered as Primary Sampling Units (PSUs) will be selected from the

set of available VHR images and in a second stage Secondary Sampling Units (SSU) will be a set of sampled points per image. In addition stratification is applied to improve the results.

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