Standard Operating Procedure (SOP)

Greenhouse Gas (GHG) – Monitoring

GreenRaise

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Introduction

Purpose

This Standard Operating Procedure (SOP) is intended to outline procedures relating to GreenRaise Consulting GmbH (GreenRaise) forest carbon projects and ensure that activities are carried out in compliance with Standard requirements. SOPs are designed to complement GreenRaise procedures and policies and specific project documents.

The Monitoring SOP is designed to track project area and carbon stock changes within stands. This information will be utilized to monitor changes in spatial forest inventory conditions and collect field data on carbon stocks. Carbon stock information will then be compared against modeled carbon stocks, where an uncertainty factor will be calculated between actual forest conditions and model projections.

The implementation of this monitoring plan may be altered throughout the 5-year period due to changes in budget, field capacity, or project workflow. The sample sizes utilized for project monitoring may be adjusted as necessary to achieve the desired level of monitoring precision. Additionally, permanent sample plots may be added to supplement the sampling program or to compensate for any unexpected losses which may occur.

Scope

This SOP applies to the Projects carried out in accordance with AFOLU project types: Afforestation, Reforestation and Revegetation (ARR) and Improved Forest Management (IFM) under the Verified Carbon Standard (VCS).

The methodologies outlined in this document are congruent with the Canadian National Forest Inventory and the Verified Carbon Standard (VCS) VM0012 and VM0010 methodologies. While these standards are not explicitly designed with the intent of submission to the Canadian Carbon Budget Model (CBM-CFS3), these standards capture all the necessary information to update the model in subsequent measurement periods. Additionally, ground verified carbon stock data will be used to verify carbon budget model projections. The standards outlined in this SOP will also be used to fulfill the monitoring requirements created by the Verified Carbon Standard.

Monitoring – Project Area

Changes within project areas will be observed using remote sensing and ground verification on an annual basis. Operational reports will also be used to identify any loss or gain to the project area. Where a loss event[1] has occurred in a Project area, the most recent procedures for reporting as stated in VCS Standard will be followed.

Remote sensing methods include the use of satellite and aerial imagery, aerial observation, and aerial to ground-based global positioning system (GPS) mapping. When changes to the project area are identified using remote sensing, crews will inspect and verify these changes on the ground using GPS units to trace the boundary of the suspect area.

The spatial monitoring program aims to identify natural disturbance events > 4ha, planned project activities such as harvests, road construction and reforestation, and unplanned anthropogenic ("human-caused") disturbances such as illegal or unplanned harvests. Once a change in the project area has been verified, it will be documented in further detail. Information reported includes the date, description of the affected area, cause of change (natural vs anthropogenic disturbance), description of the change, maps, figures of the disturbed areas, if any, and date of the change if available. The results of each monitoring period will be documented and dated for future reference in the project monitoring report.

Changes in vegetation cover will be monitored by comparing temporally different satellite images and their respective derived normalized difference vegetation indices (NDVI). The resulting analysis renders either an increase or decrease in vegetation cover which can be classified and symbolized according to the magnitude of change. Changes are measured at the pixel scale of the imagery (20 m x 20 m for Sentinel2-2LA Imagery). Project monitoring will only track vegetation losses of at least 0.5 ha in area (12.5 continuous pixels). All vegetation losses of this size or greater will contribute to the 4-ha minimum disturbance size.

Data Acquisition

To account for seasonality of vegetation cover, imagery from different years within a close seasonal range will be selected for analysis. Cloud cover limits range between 0 and 3% and any localized cloud cover is checked to not overlap the project area. Imagery from different years, but the same month optimally will be selected based on data availability and the above criteria. The satellite Sentinel2-2LA does not have a regularly scheduled fly by period over geographic areas so the timing will have some variations.

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[1] Any event that results in a loss of more than 5 percent of previously verified emission reductions and removals due to losses in carbon stocks. See VCS Program Definitions v4.2.

Monitoring – Carbon Stock

Permanent Sample Plots (PSP)

Plot Development

Several forest measurement protocols can capture the data required for forest inventory and carbon budget modelling. Permanent Sample Plots (PSPs) allow for the collection of baseline scenario data and track tree growth and stand composition changes within the forest stand. Additionally, PSPs allow for the tracking of stand successional processes by following tree growth, mortality, and regeneration.

Permanent Sample Plot locations must be distributed among and be representative of all project Analysis Units (AUs). The project proponent has the option to further stratify modeled polygons or analysis units to facilitate efficient field carbon stock monitoring. Projects may need to further stratify modeled polygons or analysis units to gain sampling representation within analysis unit age classes. For example, an analysis unit might include similar forest type polygons that range from 40-200 years. For monitoring plot sampling, the analysis unit would likely need to be stratified into age classes with similar stand carbon content. Any stratification undertaken for monitoring purposes must be documented and justified, including identifying any variation from stratification made for modeling.

A design target of establishing enough plots such that the estimate of carbon stocks across all polygon or analysis units will lie within 10 percent of the true value of the mean at the 90-percent confidence level. The locations of each PSP were randomly assigned using GIS processing within the analysis unit. Plots will be permanently marked for future measurements.

Several tools will be required for the establishment of PSPs and the measurement of plot features. A list of required tools and their purpose is provided below.

Tool	Purpose
GPS+Compass	Determining and locating plot centre, walkthrough method
11.28m plot cord	Determining plot area
Metal or wooden stake	Marking plot centre
Blue flagging tape	Marking plot perimeter trees
Blue spray paint	Marking plot perimeter
Pink flagging tape	Marking tie points
Vertex (or equivalent measuring tool	Measuring tree heights

Forestry tape	Measure tree diameter
Tree tags	Used to track trees eligible for (re)measurement
Measuring tape	Used for 50m lying deadwood transects
Hand saw[2]*	Sampling lying deadwood
Sampling bags*	Bags large enough to hold 5cm x 5cm x 5cm deadwood samples. A minimum of 30 bags will be required per species
Small shovel or hatchet*	Striking lying deadwood to determine decay classes

Plot Location and Identification

The specific location of each PSP will be determined after the formation of analysis units within the project area. Each analysis unit must have representation within the PSP measurement program. Plot formation and stratification may be updated based on the project area monitoring.

Once the number of plots and their distribution has been decided, plot locations will be identified using GIS processing. To ensure that plots are located without bias, plot centres will be assigned a random UTM coordinate within the analysis units. Each plot will receive a unique identification number for future monitoring. The numbering regime will be provided in the plot number and location list.

Plot Centre

Plot centres will be identified in the field utilizing GPS units. It may be beneficial for the sampling crews to identify navigation tie points as a reference for PSP locations. Possible tie points include road intersections, bridge or stream crossings, timber boundaries, major water bodies and water body junctions. Tie points should be placed on permanent landscape features, such as trees or rock features. Brightly coloured flagging tape or spray paint is a suitable method of marking tie points.

Once ground plot centre has been reached based on the predetermined UTM coordinates, the plot centre will be marked using a pin or stake. An aluminum tag will be attached to the centre stake where the plot number will be recorded. If the plot centre cannot be established at that location, for safety reasons only, the sampling crew will relocate plot centre 5m to the west. This process will be repeated until the plot centre can be established without inhibition. If this process cannot be achieved by moving west, the process will be completed to the north, east, or

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[2] Handsaws and sampling bags may not be required if a verifiable source of deadwood densities for decay classes are available. See 'Lying deadwood' below for additional details.
* These supplies will not be required when lying deadwood sampling is not required. See 'Lying deadwood' below for additional details.

south depending on the location of inhibiting features of the landscape. The new plot centre location will be reported, and a note will be made describing the relocation process.

Plot Establishment

Following the location of plot centre, crews will establish the sampling plot. A metal or wooden stake will be used to mark the plot centre. The sampling plot will be a 400m^2 circle, which can be established using an 11.28m plot cord. Crews will mark the perimeter of the plot by marking perimeter trees with blue flagging tape or spray paint. Perimeter trees with greater than or equal to 50% of the main stem within the plot will be considered within the plot.

Edge Plots

Plots located at the edge of a polygon or analysis unit will be included to reduce sampling bias. Edge plots will be addressed using the "walk through method", which are used when sample plots overlap between different polygon/ analysis unit. Where the boundary is diffuse/ indistinct the boundary should be defined in the field using professional judgement based on the defining character of the Analysis Unit (e.g., species, age class or site productivity and related indicators).

When an edge plot is being established, the area of the plot that lands outside the mapped stand boundary is mirrored, or flipped, back inside the stand within the plot. Trees that are in the mirrored area of the plot are recorded twice. All other trees in the plot are recorded once (See Method and Figure 1 below).

<u>Walkthrough Method:</u>

The walkthrough method is based on a description of the procedure from Dr. Iles' book entitled "A Sampler of Inventory Topics". If a boundary tree is "in", apply the walkthrough method and record its details once or twice as identified in the following procedures:

1. Measure the direction and distance from the plot centre to the centre of the "in" tree.
2. Then measure an equal distance beyond the centre of the tree in the same direction.
3. Record the tree details twice if the measurement is outside the compartment. Record sequential tree numbers for the tree if measured twice.
4. Record the tree details once if the measurement is inside the compartment.
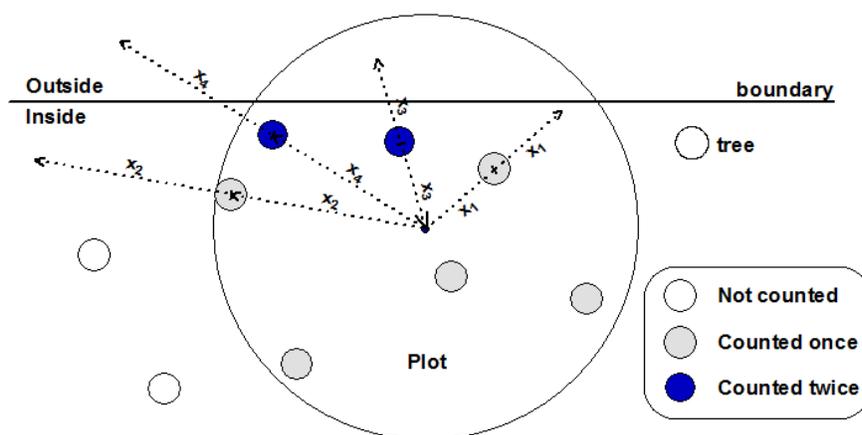
Figure 1: Walkthrough Method - Regular Boundary

Overstory Tree Measurements

Tree carbon stock for each species shall be estimated using allometric biomass equations which require diameter at breast height (DBH) and height measurements. All living trees within the sampling plot which have a DBH greater than or equal to 5cm shall be measured. Each tree will be tagged and numbered for future reference. Tree tags should be metal and attached to low hanging branches for ease of identification. Tree tags should be loosely tied to branches to reduce damages to the tree. Data recorded for each tree must include tree species, DBH (cm) measured at 1.3m and height (m).

DBH measurements for forked trees will differ depending on the location of the stem fork. Trees which fork below DBH will measured as two trees. Trees which fork at DBH or above are considered a single tree and will be measured directly below the fork, as close to 1.3m as possible.

During sampling procedures, field crews will record the tree tag number, species, tree height, and DBH measurements. This information will then be used for species specific allometric biomass equations using published equations. The allometric equations are representative of each tree species and their specific ecotype for the project location.

Following the completion of allometric volume equations, biomass estimates at the tree level will be converted to area-based stand-level measurements (t d.m ha^{-1}) using the appropriate plot multiplier (e.g., x25 for a 400m^2 plot).

Average aboveground biomass for measured polygon, i, in year, t (BAG,i,t) is determined by converting the aboveground, tree-level measurements (kg biomass per tree) to area-based, stand-level measurements (t ha-1). This is achieved by summing the aboveground biomass of all the trees within a sample plot, converting kg to t, and then dividing the sum by the plot area in ha. All plots within a particular polygon should be averaged to get an average estimate of stand-level aboveground biomass (t ha^{-1}).

Finally, the average measured carbon stock in living tree biomass for measured polygon i, time t, (CLB,i,t) is calculated as shown in equation 28c (VM0012 LtPF Methodology, Section 8.2.3).

This value of CLB,i,t must be compared to the equivalent calculation of live biomass ($LBPRJ,i,t$) calculated in the project scenario (VM0012 LtPF Methodology Section 8.2.5) (see comparison method and steps below).

Dead Organic Matter[3]

Standing Deadwood

Standing deadwood within the plot will be measured using the same method as live trees. Measurement records will differ by including a description of and an estimate of the percentage of branches and twigs remaining on the standing deadwood. This is an important distinction for biomass calculations. Branches will be classified in proportion to their size of the standing dead tree so that biomass can be reduced accordingly. When a standing dead tree has no branches, biomass will be estimated from basal diameter measurements, height, and an estimate of top diameter.

Standing deadwood biomass will be estimated using the same species specific allometric equations used in live tree biomass calculations. Ocular estimations will be made of the percentage (fraction) of tree biomass missing from stem and branches lost from the tree. Similar sized trees in the area will be used as the ocular reference. Percent biomass loss will be calculated using the following formula:

Snag DOM = Tree biomass * (100 – percent of biomass missing from snag)

After the biomass (kg biomass DOM snag^{-1}) calculation for all standing deadwood within the plot has been completed, the value will be converted to area-based stand-level measurements (t d.m ha^{-1}) using the appropriate plot multiplier.

Lying Deadwood

Lying deadwood will be measured using four 25m transects which run at 90-degree angles to each other across the plot centre at cardinal bearings. The first transect will start at a bearing of 0 (north) and each additional transect will be placed at a 90-degree angle relative to the previous. Transects will begin at the plot centre.

If the transects are obstructed by a large feature (e.g., cliff or gully) which cannot be avoided, the remaining transect length will be completed as a mirror plot and reflect toward the plot centre. Similarly, transects which reach the edge of a polygon will be completed as a mirror plot. Field crews must record and mark the transect bearing and indicate if the mirror method was used for remeasurement purposes.

Three diameter classes of CWD will be measured at the intersected points along the transects within specific radius sizes. The size class sampled along transects were as follows:

1. 0m to 5.64m radius all CWD diameters >= 5cm.

2. 5.64m to 11.28m radius all CWD with diameters >=12cm

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[3] Dead Organic Matter pools are not applicable for VM0010 measurements in the project scenario. Baseline scenario measurements will require deadwood sampling if the project proponent cannot provide them. Any forest inventory data used for VM0010 baseline scenarios must be a maximum of 10-years old. See the VM0010 methodology for further details.

3. 11.28m to 25m radius all CWD with diameters >= 30cm

Monitoring crews will be required to identify the species of the lying deadwood where possible. Deadwood will be assigned to one of three density classes:

1. Sound
2. Intermediate
3. Rotten

Each density class corresponds to a specific conversion factor used in biomass calculations. Classification of deadwood can be completed by striking the material with a strong, sharp blade.

- Sound wood will deflect the blade
- Intermediate wood will receive a slight mark or sink into the wood
- Rotten wood will fall apart when struck

Deadwood biomass will be determined for each species and each decay category as described in the VCS VM0012 methodology.

The density of lying deadwood for each species encountered will be determined at the project level. Where published and verifiable source of deadwood densities for decay classes are available these may be used and reference accordingly.

If density class must be recalculated, the following methods will be followed:

- Monitoring crews will collect a minimum of 10 samples per decomposition classification per tree species. Samples will measure a minimum of 5cm x 5cm x 5cm. Monitoring crews can remove samples using a small saw or knife, after diameter measurements have been collected. Samples shall be placed in a plastic bag, indicating the analysis unit, species, and decay class. Following harvesting, wood samples will be dried for 48 hours or until a consistent weight in grams (g) is achieved prior to density calculations.
- Wood density in each decay class (DLDW,c) will be calculated as follows:
  $$density = \frac{mass\ (g)}{volume\ (mL)}$$
- Sample volumes will be calculated using the water displacement method. A known volume of water will be placed in beaker with mL indicators. The sample will be fully submerged in the container and the new volume of water will be recorded. The difference between the initial volume and final volume will be recorded and represents the sample volume.
- Density calculations will be averaged among the samples taken for each decay classification for each species.

The total mass of lying deadwood for each analysis unit will be calculated as the average of all transects measured for that analysis unit. The mass of lying dead wood (LDW) will be calculated utilizing the following equations:

$V_{LDW,c} = \pi^2 * [(d_1^2 + d_2^2 \ldots d_n^2)\ /\ 8L]$

Where:

d_1, d_2 and d_n = diameter (cm) of each of the n pieces intersecting the transect line

L = the length of the line (100m total line length recommended by Harmon and Sexton 1996)

$M_{LDW,c} = V_{LDW,c} * D_{LDW,c}$

Where:

$V_{LDW,c}$ = the volume per unit area calculated for each density class (above)

$D_{LDW,c}$ = the density of LDW in density class, c (t d.m. m^{-3})

The total mass of LDW within each plot will be summed over all density classes:

$DOM_{LDW} = \sum M_{LDW,c}$

Where:

$M_{LDW,c}$ = the mass of lying dead wood in density class, c (t ha^{-1}).

Quality Control

A crucial portion of the quality control measures for data collection is training field crews and maintaining accurate training records. The project proponent will ensure that field crews are properly trained in sampling methods and that training records are maintained. Additionally, all quality control measures will be documented and filed with the project documents to verify completion.

Auditing checks will be completed during and after the monitoring processes. The first check will occur during the sampling procedures in which auditors will observe field crews during data collection. This can be completed during training to ensure crews are collecting data appropriately. Subsequent checks will occur when field crews are not present and include remeasurements of field plots and quality control of submitted data.

Field Measurements

Following field measurements, independent contractors who are trained in the sampling protocols will perform quality control on 10% of sample plots. All variables within the plot will be remeasured to ensure that the submitted data meets the required measurement accuracy for that variable. Minimum threshold errors in measurement error are listed below:

1. Height (standing live and dead): ± 10% standard error at 90% confidence interval (CI)
2. DBH (standing live and dead): ± 10% standard error at 90% CI
3. Tree count: ± 10% standard error at 90% CI

Laboratory Measurements

Laboratory measurements are only applicable if they are used to measure the density of collected lying deadwood. Quality control on this process involves the calibration of all instruments used as per manufacturers instructions. During the quality control process, 10% of the collected samples will be remeasured. Measurements must be within ± 10% standard error at 90% CI.

Data Entry

Quality control measures must be taken for data entered to databases operated by the project proponent. Like the field measurements, 10% of the plots completed will be verified to data accuracy during submission. All data submitted for the selected plot will be verified with the raw field data. If anomalies in the submitted data have been identified, they will be rectified with verification in the field if possible or omitted from the analysis.

Data Archiving

Data archives will be maintained by the project proponent for 2 years following the duration of the project. The data archive will include the following information:

- Original copies of field measurements, check plots, laboratory data, and related data summaries
- Copies of monitoring data analysis, models, model input and output data files, carbon calculations used for the methodology, GIS inventories for each project year, and copies of monitoring reports
- A record of any software changes and the relevant change history for the software or storage media. This shall be identified for each monitoring period.

Leakage Monitoring

Activity shifting leakage monitoring will require the project proponent to report the "demonstration of activity shifting" annually. Market leakage monitoring requirements will depend on the selected option:

1. Market Leakage Option 1 – VSC Default Market Leakage Discount Factors
    - No further leakage monitoring required
2. Market Leakage Option 2 – CAR Market Leakage Factor (not applicable if using VM0012 methodology)
    - The project proponent will annually update the leakage calculation using the most current project plan harvest levels.
3. Market Leakage Option 3 – Leakage Assessment Tool
    - Project proponents must re-evaluate the data calculations at each verification

Monitoring Interval

All plot measurements and their associated data collection will be completed in intervals of less than 5 years. Spatial monitoring and leakage monitoring will be completed annually.

Carbon Stock Calculations and Updates

Data collected through monitoring will be used to complete the following:

1. Update inventory data within the project area and related modeling and monitoring stratifications
2. Update leakage calculations
3. Update the inventory error estimates used in the calculation of the uncertainty factor
4. Update and improve carbon stock calculations

Updating Monitoring Polygons

Polygon assignment to specific analysis units and ex-post stratification must be updated on an annual basis and prior to each verification period. This process is necessary to compensate for the following issues:

1. Errors in inventory data from field sampling or other monitoring. Should the criteria used to allocate polygons to analysis units be inaccurate, the polygon must be updated and re-assigned accordingly. All non-de minimis updates due to inventory errors will require recalculation of the annual project emissions and the annual baseline emissions prior to the subsequent verification.
2. Alterations to the spatial inventory from monitoring for natural disturbance and planned/unplanned project activities. Updates to the project area will be made for all monitored events which affect the criteria used to define polygons or analysis units in the project inventory. Disturbance and activity events may result in the formation of a new polygon, stand reclassifications, or re-assignment of the polygon. Such changes will affect the calculation of carbon emissions in the project scenario.
3. Established polygons can be merged if the original justification for their separate creation is no longer applicable. These updates will only affect the calculation of carbon emissions from the project scenario.

References

Pearson, T., Brown, S., & Birdsey, R. (2007). *Measurement guidelines for the sequestration of forest carbon.* USDA For Serv., North. Res. Station. Gen. Tech. Rep. NRS-18.