Draft VCS Module

M0183

PERFORMANCE METHOD FOR REDUCED IMPACT LOGGING IN NATURAL FOREST OF THE NORTHERN REPUBLIC OF THE CONGO

Draft Version

11 March 2025

Sectoral Scope 14: Agriculture, forestry, and other land use (AFOLU)

This draft methodology was developed by The Nature Conservancy.

CONTENTS

1 SUMMARY DESCRIPTION

This module is used in conjunction with VCS methodology *VM0035 Methodology for Improved Forest Management through Reduced Impact Logging*, specifically to account for GHG emission reductions obtained with the implementation of RIL-C practices in natural forests of the northern Republic of the Congo. The module is also based on the VCS modules *Performance Method for Reduced Impact Logging in Tropical Moist Forest of the Yucatan Peninsula* and *VMD0047 Performance Method for Reduced Impact Logging in East and North Kalimantan*.

This module describes the derivation of baseline impact parameters that quantify average impacts of felling, skidding, and hauling operations for forest management. Additionally, the module provides procedures for monitoring logging impacts within the project boundaries, which set the performance against the baseline impact parameters described herein. All baseline impact parameters established in this module are valid for ten years after module approval, at which time they must be re-assessed, and this module will be updated.

A combination of factors in the business-as-usual rates of logging result in emissions that can be reduced through RIL practices, including:

- Poor training and adoption of directional felling practices that often result in greater number of trees being damaged per felled tree;
- Wide road corridors built to ensure solar irradiation of road surfaces for drying during seasonal rainfall;
- Routine use of high-impact skidding equipment and methods, including bulldozers for clearing skid trails and felling gaps and skidding without the aid of long-line cables;
- Lack of detailed skid trail planning, and training and supervision of skidder operators to follow optimal log extraction routes for efficiency. Evenly spaced, consistently branching skid trail networks with few loops and parallel paths decreases skidding damage and emissions; and
- Use of ad-hoc yarding areas along skid trails and haul roads.

2 SOURCES

This module is used in conjunction with VCS methodology *VM0035 Methodology for Improved Forest Management through Reduced Impact Logging (RIL-C)*. It is based on the VCS modules *Performance Method for Reduced Impact Logging in Tropical Moist Forest of the Yucatan Peninsula* and *VMD0047 Performance Method for Reduced Impact Logging in East and North Kalimantan*.

3 DEFINITIONS

Collaterally Damaged Trees
Trees that have been accidentally damaged as a direct result of logging activities, e.g., damage from a skidder or from impact from a felled timber tree. In the context of logging impacts, this refers to the total number of trees damaged by a certain activity. See Appendix 2 for more details.

Concession
Land leased by a company from a government for the express purpose of harvesting and managing timber. When used singularly, the term concession refers to a specific parcel of land leased from the government for the express purpose of harvesting and managing timber.

Diameter at Breast Height (DBH)
Diameter of a tree taken at the standard height of 1.3 m above ground level.

Felled Tree
A tree specifically cut for harvest (i.e., not cut or killed due to skidding operations or collaterally killed from felling nearby harvest trees). Felled trees are indicated by the presence of a chainsaw-cut stump of commercial size.

Forest Management Plan (FMP)
A site-specific plan that guides the management of a forest for timber and related resources (e.g., water, wildlife, etc.) on land where forestry- or conservation-related activities and practices are the primary use of the land.

Harvest Area (A_t)
The forest area in year t that is accessed by haul roads and skidding equipment (parameter A_t referenced in *VM0035*). In the case of the forest in the northern Republic of the Congo, this is the total area of the harvest block (also known as a parcelle) being sampled for skid trails and harvested trees.

Harvest Tree
A felled tree that has had a portion of its trunk extracted from the felling site.

Winch Skidding Systems
Use of winch cables extended >10 m into minimally disturbed vegetation for the purpose of skidding logs out to the main skid trails

Killed Tree
A tree that has been killed as a direct result of logging activities, e.g., damage from a skidder resulting in mortality. In the context of logging impacts, this definition is based on the empirical

statistical likelihood of tree mortality based on the damage caused by logging. See Appendix 2 for more details.

Logging Landscape
The geography, class of actors/sector, major logging system (e.g., selective harvest) and timeframe within which the relationships of the impact parameter (with emission reductions) are applicable, and which is defined in the corresponding region-specific RIL-C performance method module.

Major Branch
A branch, the diameter of which is at least one third of the diameter of the main stem it emerges from.

Reduced Impact Logging for Climate (RIL-C)
Application of timber harvesting guidelines designed to minimize the deleterious environmental impacts of tree felling, yarding, and hauling, specifically to achieve climate mitigation.

Sub-Block
A smaller area for sampling within the harvest area, delimited to monitor skidding impacts.

4 APPLICABILITY CONDITIONS

This module is applicable under the following conditions:

1) Project is located in the logging landscape in the northern Republic of the Congo shown in Figure 1.
2) The project area is within a concession where logging is done with proper government authorization and a current, approved Forest Management Plan (FMP). Throughout the crediting period, the concession must actively follow their FMP and remain compliant with all relevant federal and state regulations in the Republic of Congo.
3) Logging is done based on a selective silvicultural system where harvests follow all applicable government regulations, e.g., cutting diameter limits for high-value timber species such as sapelli.

This module is not applicable under the following conditions:

4) The project activity involves a deliberate reduction in harvest levels.

5) When felled tree density, FTD_t, is below 0.25 trees/ha[1] (as measured at the annual cutting block level), in which it is assumed that a deliberate reduction in harvest level has occurred.

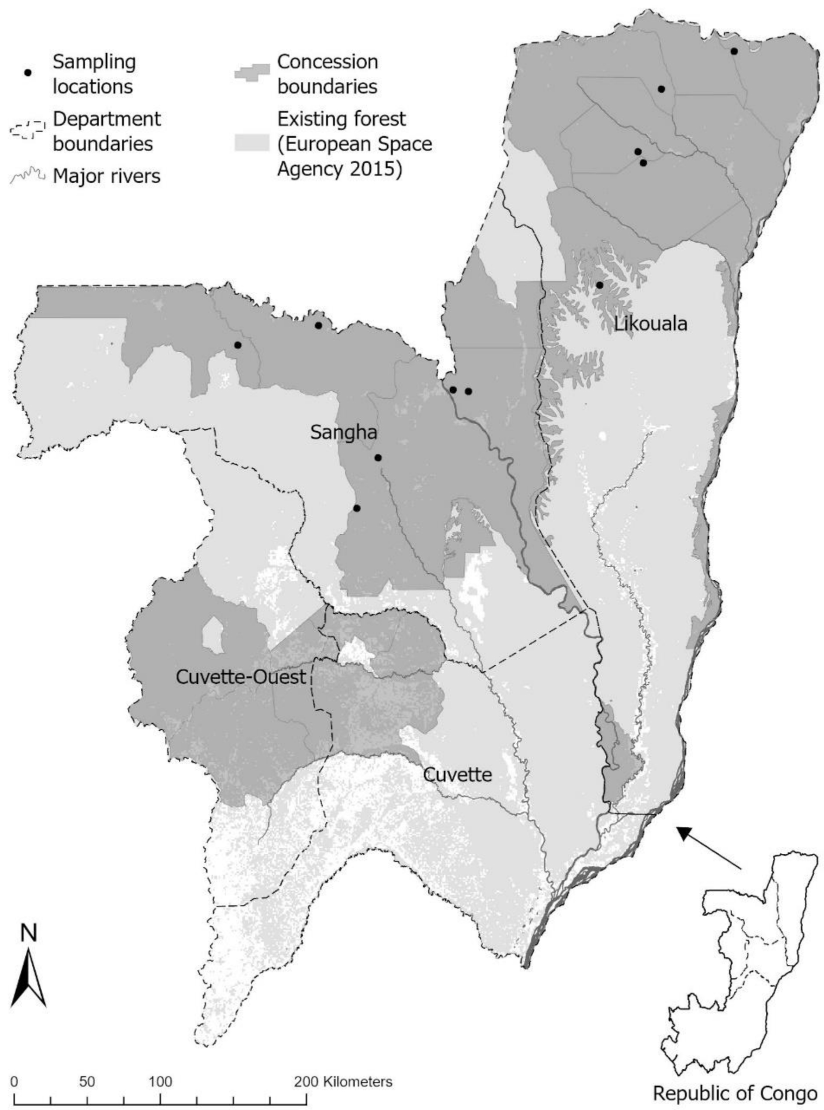

Figure 1: Logging landscape in the northern Republic of the Congo, within which parameters set out in this module are applicable (logging landscape depicted in dark grey)

[1] The threshold of 0.25 trees per hectare is a conservative estimate of the lower bound for active logging concessions in northern Republic of the Congo, based on a sample of 11 harvests at those concessions. These values were validated by participants in the stakeholder consultation (Appendix 1).

5 PROCEDURES

5.1 Derivation of Impact Parameter Crediting Baselines and Additionality Benchmarks

Crediting baselines and additionality benchmarks were established for each of the four impact parameters identified: FELL1, FELL2, HAUL and SKID (Tables 2 and 3 below).

All data presented are based on field measurements collected in 11 selected annual harvest blocks across 9 concessions in the northern Republic of Congo, all located within the specified logging landscape. Ten concessions were selected using two stratified random samples, while one was selected as a volunteer for the present study. Three of the ten stratified random selections were made as part of a global assessment of RIL-C mitigation potential, and details of that process may be found in the resulting manuscript (Ellis et al. 2019). Of note, those selections were stratified according to whether the concession was certified by the Forest Stewardship Council (FSC), to ensure representation from both certified and non-certified concessions. The remaining seven selections were made using a similarly stratified probability proportional to size (PPS) sample, which included all actively managed concessions in the northern Republic of Congo and weighted concessions by total hectares within the legally designated concession.

Within each of the selected concessions, one or more forest management planning units were selected for detailed measurements of logging activity. These selections were necessarily more opportunistic than random, with appropriate selections defined as those where 1) logging had been implemented within the preceding 12 months (to ensure field crew's ability to clearly detect stump locations, damaged trees, etc.), 2) active logging was fully completed (to ensure safety of field crews), and 3) there were at least 50 hectares of harvestable forest land (to ensure sufficient sample of harvesting damage components). Selections were made in consultation with each concession's operations staff, with explicit request from module development staff to select blocks for sampling that were in every notable way "typical".

The final sample of 11 harvest blocks included:

- 5 harvest blocks in concessions that have current Forest Stewardship Council (FSC) certification, and 6 harvest blocks in concessions without FSC certification.
- 3 harvest blocks measured in 2019 as part of the Ellis et al. 2019 study, and 8 harvest blocks measured in 2022 as part of the work explicitly intended to support this module.
- Harvest blocks sited within 9 of 13 distinct, actively managed concessions.
- Harvest blocks controlled by 8 of 9 distinct concessionaires, who collectively control all actively managed concessions in the northern Republic of Congo.

Considering the scope of logging practices and concessionaires, the module developers find the above sample represents a reasonable and conservative sample. The inclusion of 5 FSC-certified sample units within a total of 11 samples was done intentionally to create a conservative evaluation of logging impacts, based on module developers' past experience observing lower collateral damage under FSC.

Improved logging practices were identified in a previous study of Improved Forest Management in the Congo Basin (Umunay et al. 2019), which included data from three sites used in the present study. This study identified the impact parameters used herein, though specific benchmarks associated with those impact parameters will differ due to different available technologies and current practices (e.g., directional felling, skid trail planning, etc.) as well as the inclusion of additional sample sites here.

The methodology used for this study is based upon E. Belair (2022) *Field Methods: Carbon Emissions from Logging Operations in the Republic of Congo* (Appendix 3) and Griscom et al. (2014).

In all annual harvest blocks sampled, the area was sampled for harvest impacts on biomass from felling, skidding and hauling.

Based on the results of Umunay et al. (2019), the field work necessary to collect data, and a Stakeholder Workshop (September 30, 2022 – see Appendix 1) the following RIL-C practices were identified with potential to reduce carbon emissions from timber harvesting operations within the logging landscape:

1. Efficient planning and use of improved construction materials to reduce permanent forestry infrastructure (i.e. haul roads and log yards) ;
2. Improved skid trail planning;
3. Commercialization of upper stem logs (i.e. those above the first major branch) and other wood waste;
4. Improved tracking of felled trees to avoid butt log abandonment;
5. Improved use of directional felling; and,
6. Improved utilization of buttressed butt logs.

All *crediting baselines* were set at the mean value for each impact parameter, Additionality Benchmarks were set at 85% of the value of the Crediting Baselines for each impact parameter. The values for all impact parameter benchmarks and the basis for their derivation, are given in Table 1 and 3. The approach of using an Additionality Benchmark that is slightly smaller than the eventual Crediting Baseline was initially developed for the VM0035 methodology. The justification for using that approach here is the same as has been used in past iterations:

a. The Crediting Baseline is set as the mean value for each impact parameter because that is the most logical and consistent baseline to apply to all actors in a performance benchmark system. Requiring concessions to demonstrate emissions performance below the mean (Crediting Baseline), this approach incentivizes improving collateral damage from forestry operations by only rewarding those who create less damage than the average operator.

b. Inclusion of a separate Additionality Benchmark set below the mean emissions level is intended to make crediting even more conservative. Essentially, use of this lower Additionality Benchmark ensures that concessions are not credited for marginal improvements, which may be confounded by sampling or measurement error more easily than larger improvements which deviate from the mean value to a greater extent. This is intended to incentivize deeper, more difficult to achieve reductions in collateral damage from harvest.
c. This approach was justified for the VM0035 RIL-C methodology based on the intent to balance two important goals:
    i. Minimizing the ability to generate credits based on marginal improvements in forestry emissions profile or passively falling below the mean without substantial improvements, while simultaneously
    ii. Maximizing feasibility for motivated concessionaires moving towards good faith improvements in their forestry emissions profile.

5.1.1 Equations for Quantifying GHG Emission Reductions

Equations are given in Sections 5.1.1 - 5.1.4 for calculating emission reductions as a function of each of the impact parameters mentioned above and listed in Tables 2 and 3.

5.1.1.1 Procedures for Including Deductions in the Calculations of Emission Reductions as a Function of Uncertainty

Calculations of emission reductions for all impact parameters incorporate deductions for uncertainty. Deductions were made by assigning values at the bottom end of the 95% confidence intervals for key input variables used in calculating the relationship between impact parameters and emissions.

In addition to these deductions, the baselines for each impact parameter are conservative because, by including a higher proportion of FSC-certified concessions in the sample than exists in the population, a conservative bias was incorporated in the selection of the nine logging concessions sampled for source data as described above.

5.1.1.2 Procedures for Establishing a Performance Benchmark Based Upon Available Technologies and/or Current Practices, and Trends, within the Sector

The current technology employed in logging and wood extraction in the northern Republic of the Congo has not changed dramatically over the last 10 years, based on our consultations with local practitioners and experts. Trees are typically felled and bucked with a chainsaw prior to the establishment of skid trails. Skid trails are then built by bulldozers that approach the base of the felled tree, while cable or grapple skidders are then used to drag logs to yarding areas adjacent to haul roads. One major deviation from this typical arrangement is a particular concession that does not use log yards at all, but temporarily stores logs along the banks of haul roads. Even when cable skidders are employed, it is not typical for the cable to be extended beyond 2-5 meters from the skidder, so skid trails must proceed directly to the base of the log.

The first FSC certification of a logging concession in Congo occurred in the late 1990s. Currently there are three FSC certified concessions within the logging landscape, all of which were intentionally included in our sample. While FSC's Principles for Responsible Forest Management are not intended to deal directly with the generation of removals or reduced emissions, they incorporate many criteria and requirements meant to ensure positive environmental, social, and economic outcomes from forest management. Many of these criteria (e.g. minimum widths for streamside management zones (SMZs)) frequently have the effect of reducing carbon emissions from forestry and enhancing sequestration rates. For example, several concessions are applying Reduced Impact Logging (RIL) practices such as directional felling and skid trail planning, but for most of those concessions these practices are not intentional RIL practices. The biased inclusion of FSC certified concessions in the sample was intentional, and results in a conservative baseline, as explained above.

Table 1: Procedure to determine Impact Parameters

Harvest activity category	Emissions Category	Impact Parameter	Procedure to Confirm
Felling and log recovery: Includes improvements in directional felling, log extraction, and wood commercialization	Emissions from trees damaged during felling.	**FELL1**: Average number of trees > 10 cm DBH damaged per felled tree	Visual assessments of damaged trees in felling gap.
	Emissions from merchantable wood volume not extracted	**FELL2**: Average % felled log length abandoned	Visual assessments of sampled felled trees with log section extracted.
Skidding: Includes improvements in skid trail planning, low impact skidding technologies, and winch utilization	Emissions from mortality resulting from skidding damage.	**SKID**: Average number trees > 20 cm DBH damaged by skidding per harvest area (ha)	GPS mapping sampled skid trails and tally of trees damaged.

Hauling: Includes improvements in planning, building materials, and efficiency of haul roads and log yards	Emissions from mortality resulting from clearing road corridors and log landings.	**HAUL**: Area of haul road corridor and log landing per unit of harvest area (m2 ha-1).	Mapping of all haul road corridor centerlines within annual harvest block and sampling of corridor widths; mapping and GIS digitization of log yards in a subsample of the annual harvest block.

Table 2: Calculation of baseline and additionality benchmarks

Harvest Block Code	FELL1: Average number of trees > 10 cm DBH damaged per felled tree	FELL2: Average % felled log length abandoned	SKID: Average number of trees > 20 cm DBH damaged per harvest area A_t (ha)	HAUL: Area of haul road and log landing per unit of harvest area (m2 ha-1).
ROC2	8.2	-	1.9	511.2
ROC5	16.0	-	4.7	349.0
ROC6	9.6	-	2.4	623.7
ROC7	5.9	2.8	1.7	583.8
ROC8	5.8	5.8	2.9	362.7
ROC9	7.0	8.3	8.4	319.0
ROC10	6.2	5.8	2.7	330.8
ROC11	6.7	7.2	3.7	230.8
ROC12	3.8	4.3	2.6	136.8

ROC13	5.3	12.9	3.2	819.3
ROC14	4.6	1.5	1.7	180.4
Crediting Baseline (mean)	7.2	6.1	3.3	404.3
Additionality Benchmark (40^{th} perc)	5.9	5.5	2.6	330.8
Additionality Benchmark (25^{th} perc)	5.5	3.9	2.2	274.9

5.1.2 Felling Impact Parameter (FELL1): Average Number of Trees > 10 cm DBH Damaged per Felled Tree

5.1.2.1 Additionality and Crediting Baseline

Felling Impact Parameter 1 (FELL1) is the number of trees above 10 cm DBH that are damaged from felling of harvest trees. The crediting baseline for FELL1 is set at 7.2 damaged trees per felled tree, the mean value across all harvest blocks sampled.

The additionality benchmark for FELL1 is set at 5.9 damaged trees per harvest tree, which is the 40^{th} percentile of FELL1 values across all harvest blocks sampled. Based on field measurements and expert consultation, this is considered a feasible yet ambitious threshold.

5.1.2.2 Quantification of GHG Emission Reductions

Reductions in the FELL1 impact parameter below the crediting baseline results in avoided CO2 emissions, calculated using the following equation (equation 1 encompasses both f_{AGC} ($FELL_t$) and f_{BGB} ($FELL_t$) as referenced in VM0035):

$$ER_{FELL1,t} = (FELL1_B - FELL1_{M,t}) \times CDB_{FELL1} \times FTD_t \times R \quad (1)$$

Where:

$ER_{FELL,t}$	=	Total emission reductions due to reductions in *FELL* below crediting baseline within the annual harvest area at time t; tCO_2e/ha
$FELL1_B$	=	Baseline felling impact parameter 1 (FELL1); number of damaged trees per felled tree; fixed default value of 7.2 trees damaged/felled tree
$FELL1_{M,t}$	=	Measured felling impact parameter at time t; average number of damaged trees per felled tree

CDB_{FELL1}	=	Total collateral damage biomass carbon of damaged trees resulting from felling; fixed default value of 0.3319 tC / damaged tree
FTD_t	=	Felled tree density at time t; trees/ha
R	=	Ratio of CO_2 to C molecular weight; fixed default value of 44/12

Conservative default values were calculated for collateral damage biomass carbon (*CDB*) at the bottom end of the 95% confidence intervals for the respective mean values.

5.1.3 Felling Impact Parameter (FELL2): Average Percent of Felled Log Length Abandoned

5.1.3.1 Additionality and Crediting Baseline

Felling Impact Parameter 2 (FELL2) is the average percent of felled tree log length that is abandoned in the forest following harvest. The crediting baseline for FELL2 is set at 6.1 percent of felled tree log length abandoned, the mean value across all harvest blocks sampled.

The additionality benchmark for FELL2 is set at 5.5 percent of felled tree log length abandoned, which is the 40th percentile of the FELL2 parameter across all harvest blocks sampled. Based on field measurements and expert consultation, this is considered a feasible yet ambitious threshold.

The crediting baseline and additionality benchmark for FELL2 were set using only 8 harvest block samples, as the remaining 3 samples in the dataset lacked information on log abandonment.

5.1.3.2 Quantification of GHG Emission Reductions

Reductions in the FELL2 impact parameter below the crediting baseline results in avoided CO2 emissions, calculated using the following equation (equations 3 encompasses both f_{AGC} ($FELL2_t$) and f_{BGB} ($FELL_t$) as referenced in VM0035):

$$ER_{FELL2,t} = (FELL2_B - FELL2_{M,t}) \times FLB_{FELL2} \times R \quad (2)$$

Where:

$ER_{FELL2,t}$	=	Total emission reductions due to reductions in *FELL2* below crediting baseline within the annual harvest area at time t; tCO_2e/ha
$FELL2_B$	=	Crediting baseline for felling impact parameter 2 (FELL2); average percent of log length abandoned in the forest after logging; fixed default value of 6.1%
$FELL2_{M,t}$	=	Measured felling impact parameter 2 at time t; average percent of log length abandoned in the forest after logging
FLB_{FELL2}	=	Mean felled tree log biomass carbon emitted from trees felled but not completely extracted; fixed default value of 3.331 tC / ha

R	=	Ratio of CO_2 to C molecular weight; fixed default value of 44/12

5.1.4 Skidding Impact Parameter (SKID): Number of Trees ≥ 20 cm DBH Damaged per harvest area

5.1.4.1 Additionality and Crediting Baseline

The skidding impact parameter (SKID) is the number of trees greater than 20 cm DBH damaged by skidding operations per hectare of harvest area.

The crediting baseline for SKID was set at 3.3 damaged trees/ha representing the mean value across all annual harvest blocks sampled. The additionality benchmark for SKID was set at 2.6, which is the 40th percentile of the crediting baseline across all harvest blocks sampled.

5.1.4.2 Quantification of GHG Emission Reductions

Reductions in the SKID impact parameter below the crediting baseline result in avoided CO_2 emissions, calculated using the following equations:

$$ER_{SKID,t} = (SKID_B - SKID_{M,t}) \times CDB_{SKID} \times R \quad (3)$$

Where:

$ER_{SKID,t}$	=	Total emission reductions due to reductions in SKID below crediting baseline at time t; tCO_2e/ha
$SKID_B$	=	Crediting baseline value for mean number of trees > 20 cm DBH damaged per ha; fixed default value of 3.3 trees/ha
$SKID_{M,t}$	=	Measured value for skidding impact parameter at time t; mean number of trees > 20 cm DBH damaged by skidding per ha; trees/ha
CDB_{SKID}	=	Total collateral damage biomass carbon of damaged trees resulting from skidding; fixed default value of 0.46 tC / damaged tree
R	=	Ratio of CO_2 to C molecular weight; fixed default value of 44/12

5.1.5 Hauling Impact Parameter (HAUL): Area of Haul Road Corridors and Log Landings

5.1.5.1 Additionality and Crediting Baseline

The hauling impact parameter (HAUL) is the area, in square meters per ha of annual cutting block (m2 ha-1), of haul road and log landing (or yard) corridors. These corridors include both the active road and landing surfaces (bare earth) as well as the swath of forests on either side of active use surfaces that are cleared of trees for the purposes of “daylighting” to speed drying of active surfaces. Log landings (or yards) are located alongside haul roads and represent a second separate element of this impact parameter. It is conservatively assumed that the haul road and log landing emissions associated with a given annual harvest are limited to the clearing of haul road and log landing corridors within the boundaries of a given annual cutting block.

The crediting baseline for HAUL was set at 404.3 m^2/ha representing the mean value across all annual harvest blocks sampled. The additionality benchmark for HAUL was set at 330.8 m^2/ha, which is the 40^{th} percentile of the crediting baseline across all harvest blocks sampled.

5.1.5.2 Quantification of GHG Emission Reductions

Reductions in the SKID impact parameter below the crediting baseline results in avoided CO_2 emissions, calculated using the following equations:

$$ER_{HAUL,t} = \left(HAUL_B - HAUL_{M,t}\right) \times 0.0001 \times FB_{Unlogged} \times R \qquad (4)$$

Where:

$ER_{HAUL,t}$	=	Total emission reductions due to reductions in HAUL below crediting baseline at time t; tCO_2e/ha
$HAUL_B$	=	Crediting baseline value for hauling impact parameter; area of haul roads and yards per unit of harvest area; fixed default value of 404.3 m^2/ha
$HAUL_{M,t}$	=	Measured value for hauling impact parameter; area of haul roads and yards per unit of harvest area at time t; m^2/ha
$FB_{Unlogged}$	=	Forest biomass carbon prior to clearing for construction of haul roads and yards, minus roundwood extracted; fixed default value of 188.3 t C/ha
R	=	Ratio of CO_2 to C molecular weight; fixed default value of 44/12; dimensionless
0.0001	=	Conversion factor from m^2/ha to ha/ha

5.2 Procedures to Monitor Impact Parameters

The purpose of monitoring is to generate primary data (original information collected directly from the with-project area) after each harvest which describe impacts of harvest on the residual stand, from which emission reductions can be estimated. Primary data may include a combination of field and remote measurements. Following completion of timber harvesting in the treatment area, all impact parameters from all logging emission source categories must be sampled to generate primary data, and the calculated impact parameters must utilize primary data. The project proponent must apply the impact parameter monitoring procedures detailed in this section or use alternative monitoring procedures that comply with the following requirements:

- Methods applied demonstrate a greater accuracy than the monitoring procedures described in this module (e.g., remote sensing associated with high quality imagery) or;

- Methods applied are more conservative than the monitoring procedures described in this module (e.g., alternative field measurements that yield more conservative value(s) for the same impact parameter(s) .

Monitoring RIL-C impact parameters in the logging landscape of northern Congo involves accessing the annual harvest area, georeferencing and/or mapping skid trails, haul roads, and log yards; sampling skid trails for number of damaged trees; sampling the width of haul roads and the size of log yards; and sampling felled trees for collateral damage and log abandonment. A summary of required sample size is given in Table 4 below. Project proponents must adhere to the sample size requirements provided here.

Throughout the project crediting period, monitoring shall be conducted within five years after each harvest. However, given the rapid regrowth potential of forests in Congo, monitoring within 1 year after harvest is recommended.

Table 3: Sample size requirements for monitoring of impact parameters

IP Name	IP Measurement	Sample Size Requirement
FELL1	Average number of damaged trees per felled tree	≥ 100 felled trees in at least 2 sub-blocks of the harvest areas.
FELL2	Average percent of felled log length abandoned	≥ 100 felled trees in at least 2 sub-blocks of the harvest area.
FTD	Felled tree density (trees/ha)	Complete census of all sampled sub-blocks of the harvest area
HAUL	Area of haul road corridors and log landings per hectare of harvest	Haul road length: GPS tracks of centerline of all haul road corridors within an annual cutting block. Alternatively, remote sensing or GIS data can be used to directly map haul road length within annual cutting block. Haul road corridor width: 30 separate width measurements must be collected within the annual cutting block. Log yards: census of log yard area (in m^2 or ha) in at least two sub-blocks of the harvest area.

SKID: $SKID_{dam}$	Average # trees ≥20 cm dbh damaged per m skid trail. Calculated from measured parameters: L_{SKID}: length of sampled skid trail networks in harvest area (m) $Tree_{dam}$: average number of damaged trees > 10 cm DBH per sampled skid trail in harvest area (number)	Tally of all trees ≥ 20 cm DBH damaged along skid trail lengths in sampled sub-blocks totaling ≥ 5.0 km.
SKID: $SKID_{dens}$	Average length of skid trails in meters per hectare of harvest block. Calculated from measured parameters: L_{SKID}: length of all skid trail network in sampled sub-blocks in harvest area A_{SKID}: area in which skid trails were censused in sampled harvest area	Complete census of skid trail networks in sampled sub-blocks totaling ≥ 5.0 km.

5.2.1 Procedures to Monitor Felling Impact Parameters

Parameter $FELL1_t$, the average number of trees > 10 cm DBH damaged per felled tree in harvest area in year t, is monitored via a census, of ≥ 100 felled trees within at least 2 sub-blocks in the harvest area.

Parameter $FELL2_t$, the average percentage of felled tree volume abandoned, is monitored via a complete census, of ≥ 100 felled trees within at least 2 sub-blocks in the harvest area. The trees used for monitoring of $FELL2_t$ may be the same trees monitored for $FELL1_t$.Felled tree density (FTD) is measured via a complete census (100% sample) of the harvest area A_t.

5.2.2 Procedures to Monitor Hauling Impact Parameters

Parameter $HAUL_t$, the area of haul roads and log yards per unit area of harvest area in year t, is monitored using three separate measurements. A complete census of all roads in the annual allowable cutting block is used to determine the length of haul roads. A random or systematic (with random starting location) sample of 30 road corridor (where the corridor is measured as the width between the nearest standing tree trunk on either side of the road) width measurements is used to estimate the average road corridor width. Each road corridor width measurement must be collected perpendicular to the sampled road's centerline, and must measure the distance from the nearest tree bole on one side of the road corridor to nearest tree bole on the other side of the road corridor. Measuring to a tree's dripline, or any other point, is unacceptable for these purposes. Finally, a complete census of log yards in at least 2 sub-blocks of the harvest area is used to estimate the area of log yards per unit harvest area. These separate measurements are then summed to estimate the area of permanent forestry infrastructure per unit of harvest area. In the event that no log landings are used within a harvest area, the haul road length and widths are the exclusive parameters used in calculating $HAUL_t$.

5.2.3 Procedures to Monitor Skidding Impact Parameters

Parameter $SKID_{M,t}$, average number of trees greater than or equal to 20 cm DBH that have been damaged due to skidding activity per hectare in the harvest area in year t, is equal to the product of the two following monitored parameters:

$SKID_{dens,t}$	=	Average length of skid trails per hectare in harvest area at time t (m/ha)
$SKID_{dam,t}$	=	Average number of trees ≥ 20 cm DBH damaged trees per m skid trail in harvest area at time t (number/m)

Parameter $SKID_{dens}$ is calculated by dividing the total length of all sampled skid trails within the sampled sub-blocks ($L_{SKID,i,t}$) by the total area of sampled sub-blocks ($A_{SKIDi,t}$).

$$SKID_{dens,t} = \sum_{i=1}^{n} L_{SKID,i,t} \div \sum_{i=1}^{n} A_{SKID,i,t} \qquad (5)$$

Where:

$SKID_{dens,t}$	=	Average length of skid trails per hectare in harvest area at time t (m/ha)
$L_{SKIDi,t}$	=	Length of all skid trail network in sampled sub-block *i* in harvest area at time t (m)
$A_{SKIDi,t}$	=	Area of sub-block *i* sampled for skid trail length in harvest area in year t (ha)

To monitor this parameter, record the number of damaged trees ≥ 20 cm DBH along sampled skid trail networks. Note that any felled harvest trees or trees damaged through the felling of harvest trees that may be encountered in the skid trail are not included in this count. Note that any tree ≥ 20 cm DBH that was indirectly damaged due to skidding activity is included in the counts (e.g., a tree ≥ 20 cm DBH that was knocked down by a tree that was knocked down by a forestry tractor).

Parameter $SKID_{dam,t}$, the average number of trees > 20 cm DBH damaged per m skid trail in annual harvest area from year t, is calculated by weighting by skid trail network length.

$$SKID_{dam,t} = \sum_{i=1}^{n}\left(\frac{L_{SKIDi,t}}{\sum_{i=1}^{n} L_{SKIDi,t}}\right) \times \left(Tree_{dam,i,t} \div L_{SKIDi,t}\right) \quad (6)$$

Where:

$SKID_{dam,t}$	=	Average number of trees > 20 cm DBH damaged per m skid trail in annual harvest area in year t (number/m)
$L_{SKIDi,t}$	=	Length of skid trail network in sampled sub-*block i* in harvest area in year t (m)
$Tree_{dam,i,t}$	=	Number of damaged trees $\geq$ 20 cm DBH per sampled skid trail i in harvest area in year t (number)

The two component parameters are combined in the equation below to produce parameter $SKID_{M,t}$.

$$SKID_{M,t} = SKID_{dens,t} \times SKID_{dam,t} \quad (7)$$

Where:

$SKID_{M,t}$	=	average number of trees ≥ 20 cm DBH damaged by skidding activity per hectare of harvest area in year t (number/ha)
$SKID_{dens,t}$	=	Average length of skid trails per hectare in harvest area in year t (m/ha)
$SKID_{dam,t}$	=	Average number of trees $\geq$ 20 cm DBH damaged per m skid trail in harvest area in year t (number/m)

6 DATA AND PARAMETERES

6.1 Data and Parameters Available at Validation

Data / Parameter	R
Data unit	Dimensionless
Description	Ratio of CO_2 to C molecular weight
Equations	1-4
Source of data	Periodic table
Value applied	44/12
Justification of choice of data or description of	Based on fixed ratio of molecular weight

measurement methods and procedures applied	
Purpose of Data	Calculation of emission reductions
Comments	N/A

Data / Parameter	$FELL1_B$
Data unit	number of damaged trees per felled tree
Description	Crediting baseline for collateral damage caused by tree felling
Equations	1
Source of data	Calculated in module from field collected data. Data included a total of 209 trees sampled across 11 sample sites at a total of 9 concessions in the northern Republic of Congo. Data were collected in 2019 and Feb-May 2022, according to the procedures in Appendix 3.
Value applied	*7.2 trees damaged / tree felled*
Justification of choice of data or description of measurement methods and procedures applied	See Appendix 3, Part 4, Section B for full description of measurements collected for this parameter.
Purpose of Data	Calculation of emission reductions
Comments	

Data / Parameter	$FELL2_B$
Data unit	%
Description	Crediting baseline for collateral damage caused by log abandonment
Equations	2
Source of data	Calculated in module from field collected data. Data included a total of 174 logs sampled for abandonment across 8 concessions in the northern Republic of Congo. Data were collected in Feb-May 2022, according to the procedures in Appendix 3.

Value applied	*6.1%*
Justification of choice of data or description of measurement methods and procedures applied	See Appendix 3, Part 4, Sections A and B for full description of measurements collected for this parameter.
Purpose of Data	Calculation of emission reductions
Comments	

Data / Parameter	$SKID_B$
Data unit	trees/ha
Description	Crediting baseline for trees damaged per hectare as a result of skidding activities
Equations	3
Source of data	Calculated in module from field collected data. Data included a total of 95 s*kid-damaged trees* sampled on 152 skid trail plots, across 11 sample sites at 9 concessions in the northern Republic of Congo. Data were collected in 2019 and Feb-May 2022, according to the procedures in Appendix 3.
Value applied	*3.3 trees / ha*
Justification of choice of data or description of measurement methods and procedures applied	See *Appendix 3, Part 3, Sections A & B for full description of measurements collected for this parameter.*
Purpose of Data	Calculation of emission reductions
Comments	

Data / Parameter	$HAUL_B$
Data unit	m^2/ha
Description	Crediting baseline for the area of haul roads and log yards per hectare of harvest area

Equations	4
Source of data	Calculated in module from field collected data. Data included a total of 100 log yard areas, 220 road corridor widths, and a census of haul road lengths across a 450-ha sample block at each of 11 sample sites across 8 concessions in the northern Republic of Congo. Data were collected in 2019 and Feb-May 2022, according to the procedures in Appendix 3.
Value applied	*404.3 m^2 / ha*
Justification of choice of data or description of measurement methods and procedures applied	See *Appendix 3, Part 2, Sections A, B & C for full description of measurements collected for this parameter.*
Purpose of Data	Calculation of emission reductions
Comments	

Data / Parameter	CDB_{FELL1}
Data unit	tC/damaged tree
Description	Total collateral damage biomass carbon of damaged trees resulting from felling; average amount of carbon emitted from damage caused to one tree during felling
Equations	1
Source of data	Calculated in module
Value applied	Either a fixed default value of 0.3319 or calculated.
Justification of choice of data or description of measurement methods and procedures applied	The conservative default value was calculated for collateral damage biomass carbon (CDB) as the bottom end of the 95% confidence intervals based on measurements collected in northern Congo in 2022. Project area-specific estimates for CDB shall be derived from the bottom end of the 95% confidence intervals of measured stocking levels if 95% confidence intervals represent ± ≥15% of the mean - otherwise the mean estimate can be used.
Purpose of Data	Calculation of emission reductions
Comments	N/A

Data / Parameter	FLB_{FELL2}

Data unit	tC/ha
Description	Collateral damage aboveground biomass carbon due to log abandonment; mean felled tree log biomass carbon emitted from trees felled but not completely extracted.
Equations	*2*
Source of data	Calculated in module
Value applied	3.331
Justification of choice of data or description of measurement methods and procedures applied	The conservative default value was calculated for collateral damage biomass carbon (CDB) as the bottom end of the 95% confidence intervals based on measurements collected in northern Congo in 2022. Project area-specific estimates for FLB shall be derived from the bottom end of the 95% confidence intervals of measured stocking levels if 95% confidence intervals represent ± ≥15% of the mean - otherwise the mean estimate can be used.
Purpose of Data	Calculation of emission reductions
Comments	N/A

Data / Parameter	CDB_{SKID}
Data unit	tC / damaged tree/ha
Description	Total collateral damage biomass carbon of damaged trees resulting from skidding
Equations	*3*
Source of data	Calculated in module
Value applied	0.46 tC / damaged tree/ha
Justification of choice of data or description of measurement methods and procedures applied	The conservative default value was calculated for collateral damage biomass carbon (CDB) as the bottom end of the 95% confidence intervals based on measurements collected in northern Congo in 2022. Project area-specific estimates for CDB shall be derived from the bottom end of the 95% confidence intervals of measured stocking levels if 95% confidence intervals represent ± ≥15% of the mean - otherwise the mean estimate can be used.
Purpose of Data	Calculation of emission reductions
Comments	N/A

Data / Parameter	$FB_{Unlogged}$
Data unit	tC / ha
Description	Forest biomass carbon in unlogged forest prior to the construction of haul roads or log yards, minus roundwood extracted
Equations	*4*
Source of data	Calculated in module
Value applied	188.3 tC / ha
Justification of choice of data or description of measurement methods and procedures applied	The default value was calculated for forest biomass carbon (CDB) as the mean forest biomass in unlogged forests of the region, based on measurements collected in northern Congo in 2022. Project area-specific estimates for FB shall be derived from the top end of the 95% confidence intervals of measured carbon stocking levels if 95% confidence intervals represent ± ≥15% of the mean - otherwise the mean estimate may be used.
Purpose of Data	Calculation of emission reductions
Comments	N/A

6.2 Data and Parameters Monitored

Data / Parameter:	$FELL1_t$
Data unit:	number damaged trees per felled tree
Description:	Parameter for damage caused by felling in the project area; average number of damaged trees per felled tree in annual harvest area in year t
Equations	1
Source of data:	Field surveys
Description of measurement methods and procedures to be applied:	A tally of all damaged trees per felled tree sampled is kept throughout the sample, from which $FELL1_t$ at time t is calculated. Tallies are conducted in all, or a subsample of, the same skid trail networks sampled for $L_{SKIDi,t}$ and $A_{SKIDi,t}$. A complete tally shall be completed for each of the skid trail networks where a tally of felled trees is begun.
Frequency of monitoring/recording:	Within two years after each annual harvest.

QA/QC procedures to be applied:	Standard quality control / quality assurance procedures for forest inventory including field data collection and data management shall be applied. Sampling plan and standard operating procedures (SOPs) for field measurements must be documented. Procedures to randomize selection of skid trail networks for sampling shall be documented. Throughout field measurement events, an opportunistic sample of ~10% of sampled felled trees shall be re-measured to assess measurement error – average difference in collateral damaged tree count between re-measurements and original measurements must not exceed 10% of $FELL1_t$. Re-measurement for this purpose shall be done by different field personnel.
Purpose of data:	Calculation of emission reductions
Calculation method:	Divide number of trees collaterally damaged through felling by the number of felled harvest trees which were sampled for collateral damage.
Comments:	Felled trees tallied within a harvest sub-block shall include all trees felled in that area in the most recent harvest. A thorough search of the area should be made, including walking all areas within 20 m of skid trails.

Data / Parameter:	$FELL2_t$
Data unit:	Percent
Description:	Parameter for percent of merchantable log length abandoned in the forest following extraction of logs in annual harvest area in year t
Equations	2
Source of data:	Field surveys
Description of measurement methods and procedures to be applied:	A tally of log length abandoned per felled tree sampled is kept throughout the sample, from which $FELL2_t$ at time t is calculated. Tallies are conducted in all, or a subsample of, the same skid trail networks sampled for $L_{SKIDi,t}$ and $A_{SKIDi,t}$. A complete tally shall be completed for each of the skid trail networks where a tally of felled trees is begun.
Frequency of monitoring/recording:	Within two years after each annual harvest.
QA/QC procedures to be applied:	Standard quality control / quality assurance procedures for forest inventory including field data collection and data management shall be applied. Sampling plan and standard

	operating procedures (SOPs) for field measurements must be documented. Procedures to randomize selection of skid trail networks for sampling shall be documented. Throughout field measurement events, an opportunistic sample of ~10% of sampled felled trees shall be re-measured to assess measurement error – average difference in % felled trees abandoned between re-measurements and original measurements must not exceed 10% of $FELL2_t$. Re-measurement for this purpose shall be done by different field personnel.
Purpose of data:	Calculation of emission reductions
Calculation method:	Length of merchantable logs abandoned, divided by total length of merchantable logs, across all felled trees sampled.
Comments:	Felled trees tallied within a harvest sub-block shall include every third tree felled in that area in the most recent harvest. A thorough search of the area should be made, including walking all areas within 20 m of skid trails.

Data / Parameter:	$HAUL_{M,t}$
Data unit:	m2/ha
Description:	Measured value for hauling impact parameter; area of haul roads and yards per unit of harvest area
Equations	4
Source of data:	Field surveys and GIS analyses
Description of measurement methods and procedures to be applied:	The entire annual cutting block(s) should be fully sampled for haul road length in year t. If remote sensing data is used (e.g. lidar, high resolution optical), then mapping of haul roads may be completed with GIS. If field-based measurements are used, the length of all haul roads within an annual cutting block in year t should be mapped with GPS. Mean corridor width should be measured via systematic or random sampling to measure width of cleared haul road corridor and calculate average width. Note that corridor width is defined as the distance between standing, undisturbed tree trunks on either side of the road. Log yards should be censused within two sub-blocks of the annual harvest area and mapped either with GPS units in the field or GIS analysis with high resolution (≤ 2m resolution) remote sensing layers.

Frequency of monitoring/recording:	Within two years after each annual harvest.
QA/QC procedures to be applied:	Standard quality control / quality assurance procedures for forest inventory including field data collection and data management shall be applied. Sampling plan and standard operating procedures (SOPs) for field measurements must be documented. Procedures to randomize selection of road corridor width measurements for sampling shall be documented. Throughout field measurement events, an opportunistic sample of ~10% of sampled road corridor widths shall be re-measured to assess measurement error – average difference in corridor width between re-measurements and original measurements must not exceed 10% of $HAUL_t$. Re-measurement for this purpose shall be done by different field personnel.
Purpose of data:	Calculation of emission reductions
Calculation method:	Calculate average log yard area per hectare by dividing total area of sampled log yards by the total area of sub blocks sampled for log yards. Calculate average road width, and estimate average length of haul roads per hectare within the annual cutting block as the total length of haul roads divided by total managed area. Managed area in this context means the full area of all harvest sub blocks contained within the annual cutting block, less any areas permanently reserved from harvesting. Calculate average road area per hectare as average road width multiplied by average length of road per hectare. Finally, sum together average log yard area per hectare and average road area per hectare to compute $HAUL_{M,t}$.
Comments:	If remote sensing imagery and GIS analyses are substituted for field measurement of road corridor width, note that measuring from dripline to dripline of trees on the edge of roads will underestimate road corridor width. If imagery data or other remote sensing data is used for monitoring, an adjustment should be made to account for the difference between the driplines of remaining trees and the area of actual road corridor disturbance, in order to avoid underestimation of corridor widths.

Data / Parameter:	$SKID_{M,t}$
Data unit:	trees/ha
Description:	Measured value for skidding impact parameter at time t - the mean number of trees > 20 cm DBH damaged by skidding per ha

Equations	3, 7
Source of data:	Calculated
Description of measurement methods and procedures to be applied:	N/A for calculated parameter
Frequency of monitoring/recording:	Within two years after each annual harvest.
QA/QC procedures to be applied:	Standard quality control / quality assurance procedures for forest inventory including field data collection and data management shall be applied. Sampling plan and standard operating procedures (SOPs) for field measurements must be documented. Procedures to randomize selection of skid trail networks for sampling shall be documented. Throughout field measurement events, an opportunistic sample of ~10% of sampled skid trail plots shall be re-measured to assess measurement error – average difference in number of collaterally damaged trees between re-measurements and original measurements must not exceed 10% of $SKID_t$. Re-measurement for this purpose shall be done by different field personnel.
Purpose of data:	Calculation of emission reductions
Calculation method:	Calculate average number of trees ≥ 20 cm DBH damaged by skidding per meter ($SKID_{dam}$), by dividing the count of damaged trees by the total length of skid trail monitored. Calculate average length of skid trails per hectare ($SKID_{Dens}$), by dividing the length of skid trail mapped by the area of the sub blocks where skid trails were mapped. Finally, calculate $SKID_{M,t}$ by multiplying $SKID_{dam}$ by $SKID_{dens}$.
Comments:	

Data / Parameter:	$L_{SKIDi,t}$
Data unit:	meters
Description:	Length of skid trail network in sampled harvest sub-block *i* in harvest area in year t
Equations	5, 6
Source of data:	Field surveys
Description of measurement methods	Measured directly by complete census of all skid trails within the selected sample blocks. This shall include an exhaustive search withinthe selected sample block, including visual confirmation of

and procedures to be applied:	lack of skid trails in any portion of the selected harvest block that is considered “unlogged”.
Frequency of monitoring/recording:	Within two years after each annual harvest
QA/QC procedures to be applied:	Standard quality control / quality assurance procedures for forest inventory including field data collection and data management shall be applied. Sampling plan and standard operating procedures (SOPs) for field measurements must be documented and specify how field use of GPS units will avoid inclusion of spurious tracks by field crews unrelated to skid trail centerlines. GPS accuracy during field measurements shall be recorded and shall be less than 10 m. GIS smoothing procedures should be employed to eliminate GPS tracking error (which can cause raw GPS track to show small scale jagged lines which do not reflect actual skid trail centerlines).
Purpose of data:	Calculation of emission reductions
Comments:	N/A

Data / Parameter:	$A_{SKIDi,t}$
Data unit:	Hectares
Description:	Area of sub-block *i* in which skid trails were sampled within in annual harvest area in year t
Equations	5
Source of data:	GIS analysis
Description of measurement methods and procedures to be applied:	The area of the sub-block should be calculated using GIS layers from the concession’s mapping operations and should reflect the entire area of a sub-block or “parcelle” in the local phrasing. Each sub-block should be thoroughly censused for skid trails which may originate at various locations within the sub-block.
Frequency of monitoring/recording:	Within two years after each annual harvest
QA/QC procedures to be applied:	All GIS procedures applied to generate $A_{SKIDi,t}$ shall be documented. Any imagery or GIS datasets used shall be geo-referenced corner points, clear landmarks or other intersection points.
Purpose of data:	Calculation of emission reductions
Comments:	N/A

Data / Parameter:	$Tree_{dam}$
Data unit:	Number
Description:	Average number of trees ≥ 20 cm DBH damaged by skidding tallied along skid trail network i in annual harvest area in year t
Equations	6
Source of data:	Field surveys along sampled skid trail networks
Description of measurement methods and procedures to be applied:	Damaged trees are censused along the same skid trail networks measured to assess skid trail length. All damaged trees ≥ 20 cm DBH within sampled skid trail networks (≥ 5 km of skid trail length) are tallied (counted). Damaged trees are trees that have fallen to the ground, been uprooted or with trunk snapped below the first branch. Note that any felled harvest trees encountered in the immediate skid trail are not included in the counts.
Frequency of monitoring/recording:	Within two years after each annual harvest
QA/QC procedures to be applied:	Standard quality control / quality assurance procedures for forest inventory including field data collection and data management shall be applied. Sampling plan and standard operating procedures (SOPs) for field measurements shall be documented. Procedure to randomize selection of skid trail starts shall be documented. During field measurement, one sampled skid trail network will be selected for re-measurement to assess measurement error. The $Skid_{dam,t}$ parameter, calculated independently using the re-measured skid trail, shall not differ by more than 10% from the initially measured value for that skid trail. Re-measurement for this purpose shall be done by different field personnel.
Purpose of data:	Calculation of emission reductions
Comments:	N/A

Data / Parameter:	FTD_t
Data unit:	Trees/ha
Description:	Felled tree density: average of felled trees in annual harvest area in year t.
Equations	1
Source of data:	This parameter is calculated following completion of each annual harvest based on the commercial timber inventory conducted prior to each annual harvest.

Description of measurement methods and procedures to be applied:	Complete enumeration via field census
Frequency of monitoring/recording:	Within two years after each annual harvest
QA/QC procedures to be applied:	Standard quality control / quality assurance procedures for forest inventory including field data collection and data management shall be applied. Standard operating procedures (SOPs) for field measurements shall be documented.
Purpose of data:	Calculation of emission reductions
Comments:	N/A

Data / Parameter:	$SKID_{dens,t}$
Data unit:	m/ha
Description:	Average length of skid trails per hectare in harvest area in year t (m/ha)
Equations	5, 7
Source of data:	This parameter is calculated following completion of monitoring in the annual harvest block(s).
Description of measurement methods and procedures to be applied:	GPS data shall be collected at the harvest block level, with complete enumeration of skid trails within each harvest block, until a total sample of ≥ 5.0 km of skid trail length is collected
Frequency of monitoring/recording:	Within two years after each annual harvest
QA/QC procedures to be applied:	Calculated parameter – not applicable
Purpose of data:	Calculation of emission reductions
Comments:	N/A

Data / Parameter:	$SKID_{dam,t}$
Data unit:	Trees damaged / m
Description:	Average number of trees ≥ 20 cm DBH damaged trees per m skid trail in harvest area in year t
Equations	6, 7

Source of data:	This parameter is calculated following completion of monitoring in the annual harvest block(s).
Description of measurement methods and procedures to be applied:	Damaged trees shall be recorded along the entire length of skid trail sampled for parameter $SKID_{dens,t}$.
Frequency of monitoring/recording:	Within two years after each annual harvest
QA/QC procedures to be applied:	Calculated parameter – not applicable
Purpose of data:	Calculation of emission reductions
Comments:	N/A

7 REFERENCES

Belair, E.P. (2022). *Field Methods: Carbon Emissions from Logging Operations in the Republic of Congo*. The Nature Conservancy (TNC).

Ellis, P. W., Gopalakrishna, T., Goodman, R. C., Putz, F. E., Roopsind, A., Umunay, P. M., Zalman, J., Ellis, E.A., Mo, K., Gregoire, T.G., & Griscom, B. W. (2019). *Reduced-impact logging for climate change mitigation (RIL-C) can halve selective logging emissions from tropical forests. Forest Ecology and Management*, 438, 255-266.

Goodman, R.C., Aramburu, M.H., Gopalakrishna, T., Putz, F.E., Gutiérrez, N., Alvarez, J.L.M., Aguilar-Amuchastegui, N., and Ellis, P. W. (2019). *Carbon emissions and potential emissions reductions from low-intensity selective logging in southwestern Amazonia*. Forest Ecology and Management, 439, 18-27. DOI: 10.1016/j.foreco.2019.02.037

Griscom, B., Ellis, P., Putz, F. (2014). *Carbon emissions performance of commercial logging in East and North Kalimantan, Indonesia*. Global Change Biology 20: 923-937. doi: 10.1111/gcb.12386

Mokany K, Raison R.J, Prokushkin A.S. (2006). *Critical analysis of root:shoot ratios in terrestrial biomes*. Global Change Biol. 12, 84–96. DOI:10.1111/j.1365-2486.2005.001043.x

APPENDIX 1: RIL-C REGIONAL FORESTRY BEST PRACTICES STAKEHOLDER WORKSHOP

Republique du Congo

Unité – Travail – Progrès

In order to get feedback from stakeholders invested in the forests of northern Republic of Congo on the design of this module, and the specific parameters, The Nature Conservancy conducted a one-day workshop involving 31 participants composed of concession team members, forest technicians, government representatives, and non-governmental organizations to discuss the results and provide feedback. The workshop was held on September 30, 2022, via Zoom.

IFO INTERHOLCO

The Nature Conservancy
Protecting nature. Preserving life.™

CONGO EAUX FORETS ET CHASSES

Workshop Summary

The workshop was jointly organized by The Nature Conservancy (TNC) and Industrie Forestière d'Ouesso, a concessionaire operating in the northern Republic of the Congo. The workshop brought together participants from a variety of governmental agencies within Congo, numerous concession staff working in Congo, as well as environmental NGOs operating within Congo. The meeting was hosted in a hybrid format, with roughly half the group meeting in a conference room in Brazzaville and the other half attending via Zoom.

The intent of the workshop was to source feedback and input from the participants regarding the implementation of Reduced Impact Logging for Climate (RIL-C) practices in the Republic of Congo forests. To that end, the meeting began with a presentation by Mr. Peter Ellis of TNC, covering project background, history of RIL-C, field and analytical methods used, and major conclusions of the study leading to this module. Mr. Ellis' presentation gave way to a broad ranging discussion of logging practices, how RIL-C might be implemented, and what RIL-C practices might be most effective given Congo's forestry context.

Aside from conversation on implementation of RIL-C practices, the discussion also focused on the following topics, raise by the stakeholders in the meeting:

1) The desire of attendees to fully understand the data being reported before proposing methods for possible reductions in greenhouse gas emissions within the framework of RIL-C operations,
2) Potential linkages between the VM0035 RIL C methodology and the methodology for calculating emissions used within the framework of the ER-Programme 2020-2024 previously established in the Sangha and Likouala provinces,
3) The desire for an opportunity to establish Reference Levels specific to RIL-C in certified forest concessions and non-certified forest concessions,
4) The role of local communities and local populations in the process of reducing emissions related to deforestation and forest degradation in UFA Ngombé,
5) The time frame proposed by TNC to complete the analyses, publish the methodology, and communicate out the final reports before the audits of VERRA/VCS,
6) The issue of capacity building for stakeholders to assume ownership of the TNC-developed methodology for Congo.

More than 30 individuals participated in the workshop, representing several government environmental agencies within Congo, several timbe management concession managers, forestry technicians from concessions, as well as staff from the Wildlife Conservation Society and The Nature Conservancy. A full list of attendees and their organizations is presented in Table A1.1.

Table A1.1 Full list of attendees to the stakeholder workshop for the Republic of Congo RIL-C module.

LAST NAME First Name	Institutions
TATY Pierre	Ministry of Forest Economy (MEF) Directeur de Cabinet
LOUMETO Joël	MEF Conseiller
LOKEGNA Destin Loge	MEF ER-P Sangha Likouala

KIESSE Arnaud	MEF ER-P Sangha Likouala
MOUANGA Guy Frédéric	MEF Direction des Forêts
TSINGA Césaire	Rougier Mokabi
WALKER Sarah	Wildlife Conservation Society (WCS)
IYENGUE Fortuné, CTP Kabo	WCS
DIROU Sophie	WCS
TSIETA Achille	Congolaise Industrie de Bois/Olam
BIKOUMOU Séraphin	Society Thanry Congo
MBOURRA Brice	Consultation Framework for Congolese Civil Society and Indigenous Peoples (CACO-REDD)
DIHOUNKAMBA Parfait	The Network of Indigenous and Local Populations for the Sustainable Management of Forest Ecosystems in Central Africa
MOUSSELE DISEKE Guy	Dedicated Grant Mechanism for Indigenous Peoples and Local Communities
MBEMBA Jasmin	CACO-REDD
YOCKA Arthur	DDEF
LOUBILA DZATINI Brice	National Forest Inventory Agency in the Republic of the Congo (CNIAF)
MPONGUI Samuel Jean Blaise	CNIAF
MIAFOUNA Tite	MEF
BATISA Marlon	MEF Direction de la Communication
NGOMA KAYA Jean Raphael	MEF
MILANDOU Faustin	MEF Direction des Forêts
MOYO Audrey	MEF Direction de la communication
MOTOKO Dabney	CNIAF
MPIGA Saint Clair	TNC Gabon
ELLIS Peter W.	TNC Global
BELAIR Ethan P.	TNC Global
VAN LOON Tom	Interholco
BOUNDZANGA Georges Claver	Industrie Foretiere d'Ouesso (IFO)
COUTURIER Antoine	IFO
BETITO Raphael	Likouala Timber

APPENDIX 2: LIKELIHOOD OF MORTALITY ARISING FROM VARIOUS TYPES OF DAMAGE TO TREES

As part of the field measurements used to develop this module, impacts from logging damage were recorded for all trees in the samples for collateral damage from felling (FELL1) and collateral damage from skidding (SKID). Trees in the field were assigned to one of five damage classes, depending on the location and severity of the damage. In order to estimate the total biomass lost and carbon emitted from this damage, we use data from Goodman et al. 2019, which estimated the mortality of trees by damage class.

Goodman et al. (2019) tracked the outcome from 2,158 damaged trees on logging sites in Peru, categorizing the damaged trees into one of five types of damage. Table A2.1 below shows summary results from that study. Aboveground and belowground emissions were calculated for each tree in the damage scenarios as the product of the tree's above or belowground carbon times the emissions scenarios detailed in Table A2.1.

Table A2.1 Emissions scenarios for trees with various types of damage. Reproduced from Goodman et al. 2019.

Code	Damage Description	n	Mortality Rate	Aboveground Emissions	Belowground Emissions
G	Tree uprooted and lying on the ground	666	0.854	1.0	0.854
S	Tree stem snapped below the first branch	265	0.509	1.0	0.509
L	Tree leaning ≥ 10° from vertical	191	0.136	0.136	0.136
C	Tree with ≥ 50% of crown lost	914	0.115	0.407	0.115
B	Tree with ≥ 100 cm^2 of bark lost	122	0.074	0.074	0.074

APPENDIX 3: FIELD METHODS: CARBON EMISSIONS FROM LOGGING OPERATIONS IN THE REPUBLIC OF CONGO

The following protocol was developed by Ethan Belair in 2022 based on previous work by Peter Ellis, Bronson Griscom, and others, dating back to 2012.

• Introduction

This field sampling protocol was originally developed to provide field-based estimates of carbon emissions from logging among multiple commercial logging concessions in forests of Indonesia. It has since been used in numerous locations in South America, Africa and North America as well. The protocol is designed to allow comparison of emissions from different components of logging activities (i.e. hauling, skidding, felling), and different logging practices (e.g. dozer skidding vs. mono-cable winch skidding). This information will allow assessment of potential emissions reductions that could be achieved with novel combinations of logging practices.

Data collected with this protocol are intended to generate regional average values for emissions from different components, and types, of logging activities, with sampling in cutting blocks across multiple concessions; however, this protocol alone is not designed to detect statistically significant differences in emissions among concessions, which would require more sampling within a given concession.

These field methods can be paired with analysis of remotely-sensed or reported timber volume data to extrapolate field-based results and improve detection of differences among concessions, types of practices, and types of logging activities.

If aerial Lidar data is available, some elements of this field protocol can be skipped. Specifically, haul road and log landing measurements can be skipped, as well as the measurement of tree heights (as part of biomass measurements).

• Selection of concessions for sampling

Concessions should be selected for sampling across a cross section of variables that might alter harvesting practice or on the ground conditions. Expert consultation with concessionaires, government officials, or others familiar with the details of local forest harvesting practice will be critical to selecting an optimal sample of concessions for measurement. A minimum of 8 concessions is suggested to obtain minimum standard of reliability of regional estimates. More samples is always preferred.

Generate a list of all active concessions in the region of interest. It is important that this list be as comprehensive as possible, to avoid any bias created by the exclusion of particular concessions. For each concession on the list, determine:

- National origin of concession ownership
- Predominant equipment used in logging, e.g. bulldozers vs skidders

- FSC Certification status
- Province concession is located in
- Approximate annual production (categorical, low, medium, high for a given region)
- Other variables of importance, especially those likely to impact harvesting practice

Create categories of similar concessions, e.g. FSC-certified concessions in Sangha district using bulldozers in skidding operations vs non-FSC concessions in Likouala using long-line winches for skidding. Randomly select concessions from across the breadth of categories until a sufficiently large sample has been obtained.

Logistical Preparations

A recommended field team is composed of, at minimum, 3 people, providing the following functions:

- Team lead, in charge of managing field team and ensuring quality control in implementation of field methods described here. Team lead may also function as data note taker. This individual should have extensive forest inventory training and experience, and be able to make on-site adjustments to field methods to ensure unbiased sampling if unexpected conditions are encountered. This individual must have a range of technical field skills including use of the following instruments: a tape measure for tree diameter measurements, a clinometer and/or hypsometer for slope and tree height measurements, a compass to follow bearings, a prism or angle gauge for variable radius plot inventory, a GPS unit for recording geospatial coordinates, and basic GIS skills for planning field work and organizing GPS data after field work.
- Measurer 1/tree identifier. This individual should also have experience identifying commercially valuable timber species. This individual should be capable of learning to use all of the instruments mentioned above.
- Measurer 2. This individual should be capable of learning to use all of the instruments mentioned above. This individual should also be skilled with use of a machete.

All field team staff should be in good physical condition, capable of all-day hiking across steep terrain. All field staff should be equipped with all-weather clothing, shoes for steep and muddy terrain, hydration, and sun protection. The field team lead should carry a first-aid kit.

Field Equipment

The following field measurement equipment is required (minimum number of items given in parentheses). Superior equipment may be substituted.

- Tree diameter tape – metric (3+)
- 50-meter or greater tape measure (1)
- Laser or sonic range finder (1)
- Clinometer (2)
- Compass (2)
- Prisms or angle wedge gauges for variable radius sampling (2)
    - Note: Angle gauges are available in a wide range of Basal Area Factors (BAFs), and selection of BAF may be adjusted for different forests. This protocol will use two different BAFs, a smaller BAF for selecting one sample of trees to count and a larger "big BAF" for selecting a second sample of trees to measure in detail. By design, all trees that are selected with the big BAF will also be selected with the count BAF. Ideally, the big BAF should sample, on average, ~6 trees per plot and the smaller BAF should sample ~12

trees per plot. If field crews are consistently sampling too many or too few trees, they should contact the project lead to discuss a change in the protocol.

- Handheld GPS (1)
  - NOTE: We recommend a receiver that can access both GPS and GLONASS satellites and has the ability to average across several readings. We have found these units, when averaging minimum 100 waypoints, will record coordinates within acceptable ranges of accuracy. GPS data should be recorded using WGS 84 datum.
- Random number sheet: (1)
- Clip board (1)
- Pre-printed data sheets (one set of all pages for each site, plus extras)
- Rite-in-Rain pocket field notebook (1)
- Pencils for writing on write-in-rain paper (3)
- Permanent marker (2)
- Red wax tree marker (1)
- Roll of flagging tape (3)
- Extra AA Batteries for GPS, hypsometer (6)
- Machete (2)

• Part 1. Scoping

Scoping is needed in order to select and characterize cutting blocks for field sampling, within the annual cutting area. Scoping takes place prior to actual field work, either when meeting with concession staff upon arrival to base camp, or before. Concessionaire maps are used. Scoping steps are as follows:

1. Before the day of data collection, acquire from the concessionaire the concession map with boundaries of the current year's cutting blocks. If extra paper maps are not available, use the camera to photograph relevant sections of the map for reference. When at all possible, GIS data for all of the current annual cutting blocks should be obtained in advance and loaded onto GPS units.
2. Randomly select 3 adjacent, recently closed cutting blocks for field measurements from among the current year's cutting blocks. From the 3 selected cutting blocks, randomly select one "focus sample". The focus sample is intended for sampling of all components, i.e. skid trails, harvest trees, log yards, collateral damage, and haul road measurements. The remaining 2 cutting blocks are intended only for haul road measurements, which require a large area for sampling.
   - NOTE: "Closed" cutting blocks are those where all logging has been completed, post-logging inspections have been completed (if any are expected), and skid trails have been closed (i.e., cross drains installed; if any are expected). For ease of identification of stumps and collateral damage, it is recommended that the focus sample block be closed ***no longer than 6 months previous***.
3. Delineate a 50-hectare "sub-sample" portion of the focus sample cutting block. To do this:
   - Select a rectangular section of the annual cutting block that is nearest to the direction of access. For example, if the haul road to access this block comes from the east, select the eastern-most 50-hectare rectangle as the subsample.
   - Whenever possible, ensure that this sub-sample block's boundaries coincide with the existing boundaries of the block and other easy to reference locations. This makes it easier to determine the subsample location while in the field.
   - Create the subsample polygon in GIS and upload boundaries to the GPS for easy reference in the field.

- If no access to GIS is available, and there are no paper maps available that show cutting blocks, create 4 waypoints directly in the GPS unit that form a roughly 50 ha area.
    i. For reference, a 50 hs subsample would be a 707m x 707m square.
- Whatever method you use, document the 50-ha subsample for later use. This location and it's exact area is **required** for all data processing after field work is complete.

4. Identify a random starting location in unlogged forest, for later use.
    - Identify a haul road that passes through an adjacent cutting block that has not been logged since the last legal rotation, is expected to be logged within the next two years, and is a similar forest type to the sample blocks selected above..
    - Estimate the total length of those haul road sections to the nearest 0.1 kilometers.
    - Randomly select a point along this haul road length, using the random number sheet. For example:
        i. If you estimate there are 5.2 km of haul roads in the adjacent unlogged parcels, select the first two random numbers from the sheet where the first digit is less than 5 and add a decimal to create a distance. If the random numbers are 3 and 6, your random location is 3.6 km along the haul road. Then cross those digits off the random number sheet.
    - This point will be used for sampling of "unlogged forest biomass."
5. Characterize the current year's cutting blocks to be sampled, based on consultation with (i) concessionaire representatives, (ii) TNC field staff, and (iii) government and/or FSC representatives and records, with respect to:
    - Logging History: Has the site previously been logged? Approximately when?
    - FSC Certified?
    - Implementing specific "reduced impact logging" (RIL) practices (i.e. as defined by TFF)?
    - Operations: Is concession using contour mapping, harvest tree mapping, haul road or skid trail mapping to guide their operations?
    - Operations: What skidding and felling equipment is used? Take special note of non-standard logging practices, such as "Mono-Cable Winch" (MCW) system for skidding.
    - Are trees checked for hollowness?
    - Are Lianas cut before harvest?
    - Wood Products extracted: record approximate product mix concession harvests.
    - Record ownership, including use of subcontractors.
    - Describe the prevailing slope and soils found on the concession.
    - Record any other relevant information regarding logging operations.

• Part 2. Haul Roads & Log Landings

Measurements on haul roads and log landings can be made by a team of two, with a truck and driver. Thus, if more than one truck and driver are available, two teams can be mobilized to complete haul road & log landing measurements.

NOTE: GPS naming conventions are suggested below as an efficient way to identify different types of waypoints, but field personnel are encouraged to adopt their own naming conventions, as long as they are consistent, efficient, documented, and easily interpreted.

• Section A - GPS Data

1. **Point data: <u>Record GPS waypoints</u>** at the following locations in all three cutting blocks selected during "scoping":
   a) All junctions on haul road
      - Code in GPS with leading "J"

   b) All points where haul roads cross boundaries of cutting blocks
      - Code in GPS with a leading "B"

   c) Within focus block only - all skid trail junctions with haul roads
      - Code in GPS with Leading "S"

   d) Centerpoint of all log landings
      - Code in GPS with Leading "L"
      - Log landings are any location where logs are temporarily stored for pickup by haul trucks AND some modification has been made to the dimensions of the road to accommodate the stored logs. Locations where a small number of logs have been left along the road margins, but where road dimensions are not modified, do not qualify as log landings.

2. **Line data and Mapping: <u>Record GPS line data</u>** ("Tracks") for all sections of haul roads in the three cutting blocks selected.
   a) Drive haul road sections if accessible. Walk haul road sections that have been closed to vehicle access.

   b) As you collect GPS tracks for the haul roads, draw a basic sketch map of the road system based on your observations
      - Label all junctions (J), boundaries (B) and skid roads (S) encountered on the haul road system.
      - For each road section, record whether road is newly constructed for timber extraction during most recent permitting period (NEW), or previously constructed as part of an earlier harvest (OLD).

   c) NOTE: if accurate and reliable geospatial location of all haul roads in the three cutting blocks can be obtained remotely, this step can be skipped in the field. Geospatial data could be from expert consultation of recent satellite imagery, or concession GIS databases, but care should be taken to ensure accuracy and completeness of data obtained from the concession.

• Section B – Haul Road Width (primary and secondary)

Note: Begin this section when finished with all GPS data collection in Part 2, Section A.

1. Determine first measurement point
    a. Stand at a cutting block boundary (starting with the focus block), facing into the block.
    b. Select a random number between 0 and 200 using the random number sheet.
        i. Select the first three digits on the sheet which, in order, are less than 200. Then cross those digits off the sheet.
    c. Measure that distance in meters from the cutting block boundary to the point of first measurement.

2. Measure the first point.
    a. **Record GPS location**, coding with a leading "R".
        i. Document on datasheet.
    b. Measure and record the following haul road widths using a rangefinder or the measuring tape. Record measurements to the nearest 0.1 m.
        i. **Active road surface**: compacted road surface on which trucks move.
        ii. **Entire road corridor**: width measured from the nearest standing tree trunk (> 5 cm dbh) on either side of road. This measures full extent to which trees have been "felled" defined as uprooted, cut with chainsaw, or snapped below the tree crown.

3. Proceed along all haul roads at 200-meter intervals from the first point, recording GPS waypoints and two width measurements at each location.

4. Once **20 measurements of haul road width** have been completed, this section is complete. If less than 20 width measurements have been collected once all haul roads in three cutting blocks have been sampled, randomly select one of the haul road intersections with a cutting block boundary and continue haul road measurements into an adjacent cutting block until 20 measurements have been collected.
    a. To randomly select, number each of the intersections on the map, then select a random digit from the random number sheet. Go to the intersection that corresponds to the selected random number. Then cross the selected digit off from the random number sheet.

• Section C – Log Landing Dimensions

Note: Perform these measurements simultaneously with Part 2, Section B (Haul roads)

1. Determine which log landings to measure.
    a. Choose heads or tails of a coin and flip the coin. If the side of the coin chosen is successful, then begin at the first log landing that is encountered. If it is not successfully chosen, begin measurements at the second log landing encountered.
    b. Proceed along the rest of the haul road system, measuring every 2nd log landing.

2. For each selected landing, collect either digital or analog measurements of area:
    a. **Analog**: measure the following dimensions using the rangefinder, recording measurements to the nearest 0.1 m.
        i. **Width** at mid-point of landing, from edge of active road surface to closest standing tree trunk at edge of disturbed vegetation, i.e. closest tree that has not been

uprooted, cut with chainsaw, or snapped below the tree crown due to landing construction.

   ii. **Length** at mid-point of width measurement.

   b. **Digital**: Measure and record the **area** of the log yard to the nearest 1 square meter using the GPS unit or other digital device, as available.

3. Additionally, for each log landing record:
   a. **New/Old:** was this landing cleared for the most recent harvest or was it used previously?
   b. **Shape**: Classify the log landing as either half-ellipse or rectangle. If the log landing does not approximate either of these shapes, draw the shape of the log landing and measure dimensions as needed to estimate area.

4. This section is complete once **15 log landings** have been measured. If fewer than 15 log landings have been measured, begin measuring the skipped log landings from the final point at which a log landing was skipped.

Part 3. Skid Trails

Measurements on skid trails should be conducted by a team of at least 3 (one recorder, two measurers). We recommend, completing Section A, B, and C (in that order) for a given skid trail before moving on to the next skid trail. If a larger team is available, then one sub-team may perform Section A while another sub-team begins section B. Note: it is of the utmost importance that *all skid trails in the sub-sample block must be completely GPSed*.

Section A – Skid Trail Mapping and Stump Count

1. GPS Data
    a. **Note GPS waypoint starting point** at the head of the skid trail system. This point should have been mapped in section 2A above, and should be coded with a preceding "S".
    b. Walk along centerline of all skid trails in the 25 (or 50) hectare sub-sample block with GPS and acquire GPS track, including all minor spurs, within the selected skid trail network.
    c. **Collect GPS waypoint** at all skid trail
        - Intersections, code in GPS with a leading "I"
        - End points, code in GPS with leading "E")
    d. For long-line winch systems, GPS waypoints should be collected for all anchor points (locations where winch device is positioned or strapped to a tree, coded with a leading "W"). For every anchor point ("W"), randomly select one winch skid line (not including relay skid lines to other anchor points) and GPS the location of one winch end point ("WE"), defined as a harvest tree stump as the farthest extent of a winch skid line.
    e. Sketch a map of the skid trail network, marking all collected waypoints. Include elements like streams, sections with parallel skid trails, etc. (see Figure 2). For winch systems, differentiate between sections where dozer skid trails occur vs. winch skidding.

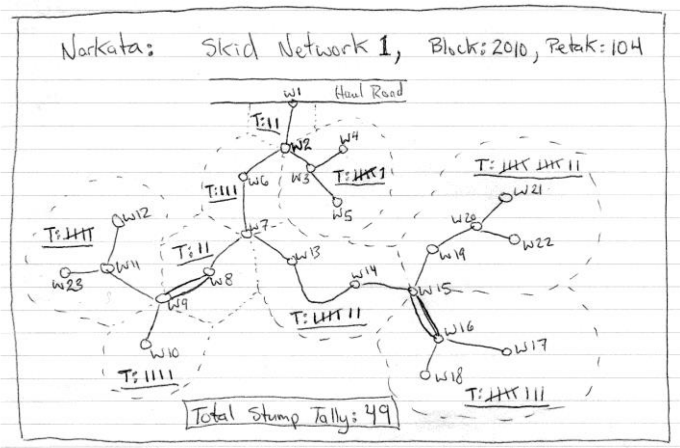

Figure 2. Example of skid trail network field diagram.

2. **Record the number of tree stumps** along the skid trail that were cut with a chainsaw during the current year, i.e. intended for commercial harvest. This includes stumps of trees that were felled, but logs were left in the forest (stump belongs to skid trail that it is closest to). Record counts on skid trail map.

   a. With the recorder remaining in the centerline of the skid trail with the GPS unit, two people should search for stumps - one person for each side of the skid trail.
      - Search thoroughly for stumps hidden beneath vegetation or slash.
      - Stumps are usually within 50 meters of the skid trails (long-line winch systems: 150 meters from anchor trees).
      - Any evidence that stumps are further out should be investigated.
   b. If long-line winch systems are involved - make two separate tallies: one for trees skidded only by dozer, one for trees skidded by MCW.
   c. If available, use maps of harvest tree positions to aid in identifying stumps.

3. Repeat skid trail mapping and stump count for *__all skid trail networks in the sub-sample block__*.

- ## Section B – Skid Trail Plots

1. Determine starting point for first plot.
   a. Stand at head of skid trail (first point where one could measure width of skid trail as distinct from haul road)
   b. Select a random number between 0 and 100, using the random number sheet.
      a. Select first two digits from sheet, use those for your random number. Then cross those digits off from the sheet.
   c. Using tape or rangefinder, measure this distance in meters, down skid trail (measuring distance along the slope) to location of the first plot.
   d. Locate subsequent plots at 100 m intervals (slope distance).

2. Establish Skid Trail Plot
   a. Put a stake in the center of the skid trail where the plot begins.
   b. Measure 10 meters (slope distance) along the skid road and mark the end of the plot.
      - NOTE: Do not correct for slope. Horizontal length of each skid trail plots will be calculated later using plot slope measurements.

3. Take the following measurements for each skid trail plot:
   a. **__Slope of skid trail__**: from the first stake, use clinometer or rangefinder to measure percent slope along the skid trail.
   b. **__Slope of land__**: At first stake, use rangefinder/clinometer to measure percent slope of land directly upslope and downslope. Average two measurements and record as slope of land.
      - Note: this measurement is the same as skid trail slope if the skid trail is oriented directly down the slope.
   c. **__Width of skid trail__**: Measure (to nearest 0.1 m), width of skid trail at upper and lower stakes. Width is determined as distance from closest undamaged, standing tree on each side of the skid trail.
   d. **__Damaged trees__**: Record all trees that were damaged by skidding operations between the upper and lower stakes. Measure diameter at breast height (dbh) of all trees >= 20 cm dbh (or as close to dbh as possible). Record dbh to the nearest 0.5 cm. Record damage code for each tree (must have at least one damage code per tree, record as many codes as appropriate):

- G: completely pushed over, to the ground, either uprooted or snapped below 1.3 meters height.
- S: snapped above 1.3 meters and below first major branch
- C: ½ or more of tree canopy removed or killed.
- B: ≥100 cm^2 of bark damaged (scraped off).
- L: leaning ≥ 10˚ from vertical due to impacts from skidding operations (do not include trees leaning due to natural causes).
- **NOTE**: A damaged tree is considered "in" the skid plot if the mid-point of the stump is between the upper and lower stakes. For uprooted trees, it is the current location of the tree that matters, i.e. if the tree is in the plot, measure it. If the stump/base of the tree is not visible, the lowest visible portion of the trunk is used to determine if the tree is "in" the plot.

4. Continue along the skid trail, measuring plots at 100-meter intervals.
   a. When junctions are reached in the skid trail network, randomly select a fork and follow that fork to continue measuring.
      - To randomize, select a digit from the random number sheet. If it is odd, go left at the fork. If it is even, go right. Cross that digit off the random number sheet.
   b. When terminus points are reached, return to prior fork in system and continue measuring new plots, preserving the distance remainder reached at terminus (e.g. if reached 25 meters out of 100 at terminus point, count 75 more meters from fork).
   c. Continue with skid trail plots until at least 15 plots have been completed. If skid trail network is fully sampled and less than 15 plots are completed, continue skid trail plots in the adjacent skid trail network of the same cutting block until 15 skid trail plots are completed. Thus, a total of at least **15 skid trail plots** should be sampled per concession, within the selected cutting block.

- ## Part 4. Harvest Tree Impacts

Harvest tree measurements should be started after skid trails have been completely mapped. This section of the protocol will collect data on the size and log utilization of **15-20** harvested trees, and the collateral damage associated with felling those trees. “Harvest trees” include all trees felled with the intention of harvesting, including those trees for which no trunk section was actually removed from the forest. “Harvest trees” do NOT include those trees that were **only** felled in order to access another tree, build a skid road, etc.

1. Determine first harvest tree gap to sample.
    a. Randomly select a number between from 1 to 3 (20% sample intensity).
        i. Select the first digit between 1 and 3 on the random number sheet. Then cross that digit off the sheet.
    b. Select a logical starting point for sampling harvest tree stumps, e.g. the first place the skid trails diverge from the haul roads.
    c. From this starting point proceed along the skid trail, counting the stumps of all commercially harvested trees until arriving at the randomly selected number. This stump is the first sample.

2. After the first harvest tree is sampled (instructions below), select every fifth stump for sampling.
    a. If a selected stump is part of a “multiple-tree gap”, where you cannot distinguish between the collateral damage due to one harvest tree vs. another nearby harvest tree, then sample all harvest trees in that gap before resuming sampling of every fifth tree. Thus, you will sample every fifth gap, which is potentially more than every fifth stump.

3. When encountering skid trail junctions, proceed first down the shorter skid trail. After reaching the end of the skid trail, return to the junction and continue counting, carrying over remainder of tree count from last skid trail fork.

4. Continue until the skid network is fully sampled.
    a. If fewer than 15 harvest trees have been sampled, continue sampling harvest trees in the adjacent skid trail network, until at least 15 have been sampled.
    b. If 15 harvest trees are sampled before the entire skid network has been sampled, continue sampling every 5th stump up to a maximum of 20 sampled harvest trees.
    c. If 20 harvest trees are sampled, the remainder of the skid network may be left unsampled.
    d. Thus, a total of **15-20 harvest trees** should be sampled per concession, within selected cutting block.

- ### Section A – Harvest Tree Measurements

Before beginning data collection, inspect all portions of the felled tree. If it appears that any section of the tree that is still present has been moved since felling, either by the logging crew, sliding down hill, etc., *do not record* the felled tree and move on to the next potential felling gap for sampling.

For each felled harvest tree sample, including each harvest tree within multiple-tree gaps and trees where all logs have been abandoned, collect the following data:

1. **Waypoint**: Acquire a GPS waypoint at the stump of each harvest tree sampled. When recording GPS coordinates, use the “average location” function to collect at least 100 waypoints at the stump.

a. Record waypoint identification number on the data sheet.

2. **Slope**: Standing at stump, measure slope upslope and down slope with rangefinder or clinometer.

3. **Azimuth**: Standing at stump, record direction of tree felling, using magnetic north, measured in degrees.

4. **Tree ID number**: If identified by tree inventory tag, record tree ID number.

5. **Species**: Record species of tree if known. Scientific / Latin names are preferred. When Latin name is unknown, record the local name. If unknown, record "UNK".

6. **Stump dimensions**: record the height, diameter(s) and hollow of the stump.
   a. Measure stump height on up-slope side of the stump to the nearest 1 cm.
   b. Measure stump diameter(s) at the top of the stump, i.e. the point where the tree was cut, to the nearest 0.1 cm.
      - If stump diameter is measured with a calipers, standard measuring tape, etc., measure at the widest point on the stump and the point perpendicular to the widest point, then average the two measurements together.
      - If stump diameter is measured with a diameter tape, a single measurement may be taken.
      - **NOTE**: if tree was cut above buttress, simply measure stump diameter at the top of the stump. If tree was cut below the buttress, if the butt log is available, measure stump diameter above the buttress. If the butt log is not available, measure at the top of the stump.
      - See Supplementary Figures 1 and 2 for stump measurement details.
   c. Diameter of hollow. If stump is hollow, measure the diameter of the hollow section to the nearest 0.1 cm using a standard measuring tape.
      - If hollow is not circular, measure at the widest point of the hollow and the point perpendicular to the widest point and average the two measurements together.

7. **Diameter at breast height (dbh)**: At the point that would have been 1.3 meters aboveground, measure diameter of the stump or log to the nearest 0.1 cm using a diameter tape.
   a. If the top of the stump is higher than 1.3 m, measure dbh at the appropriate location on the stump.
   b. If the top of the stump is lower than 1.3 m and the butt log is present, measure dbh at the appropriate location on the butt log.
   c. If the top of the stump is lower than 1.3 m and the butt log is absent, record the stump diameter as dbh.
   d. Avoid measuring in locations that have a large wound, bulge, or branch. See Supplementary Figure 3 for detailed instructions on where to measure unusual trees.

8. **Total Tree Height.** Measure total distance from stump base to top of crown, to the nearest 0.1 m.

   a. **Remember**: If there is any indication that the tree sections that are still present were moved after felling, do not record the felled tree and move on to the next potential felling gap for sampling.

9. **Log section dimensions**. For each separate section/log of the felled tree collect the measurements below. Start with the stump, then move in order up the tree, recording each section of the tree, whether it is present or absent (see Supplementary Figure 4 and 6). For each section, record:
   a. Whether each log is present or absent, i.e. whether it was left in the woods or skidded out.
      - If all log sections remaining appear to account for the entire tree, mark that no log sections were extracted from forest.
   b. Top and Bottom Diameter of the log, to the nearest 0.1 cm.
      - If diameter is measured with calipers, measure at the widest point and the point perpendicular to the widest point and average the two measurements together.
      - If diameter is measured with a diameter tape, a single measurement may be taken, recording the same measurement for both stump diameter 1 and 2.
      - **NOTE**: For adjacent logs, the top diameter of the lower log should roughly equal the base diameter for the upper log (see Supplementary Figure 5)
      - **NOTE**: If a log has already been skidded out of the forest, estimate its diameter based on the sump or logs which would have been in adjacent portions of the tree, which are still present (see Supplementary Figure 7).
      - **NOTE**: Avoid measuring diameters at wounds, bulges, or branches. If a defect is at the end of the log, offset measurement a short distance to where the defect is not present (see Supplementary Figure 8)
      - **NOTE:** If the diameter of one section is significantly different from the adjacent section due to a split or branch (see Supplementary Figure 9), note this on the data sheet and continue measuring the largest section of the log after the split.
   c. Length of the log, to the nearest 0.1 m.
      - Note that for extracted log sections, length can be estimated as the distance on the ground between other, present log sections.
   d. Condition of log: hollow, waste, and/or cracked log.
      - If the log is hollow, measure at the widest point of the hollow and the point perpendicular to the widest point and average the two measurements together.
         - For logs that are completely hollow, measure at the top end of the log.
      - If the log is marked as present, but meets general local standards for commercial timber, mark the log as "waste."
      - If the log is not utilizable primarily because it was cracked during felling, mark the log as "cracked".
      - NOTE: if uncertain, consider all logs commercial timber if they are:
         - From 0.3 m aboveground or immediately above the buttress (whichever is closer to the ground) to the point where the log is smaller than the minimum merchantable cutting diameter.
         - Free from large branches or defects.
         - Greater than 4 m in length.

• Section B – Collateral damage to residual stand

For each tree ≥ 10 cm dbh that was damaged by the felling of sampled harvest tree(s), record the following information:

1. **Diameter at breast height (dbh):** Measure diameter of the stump or log to the nearest 0.1 cm, at the point that would have been 1.3 meters aboveground, using a diameter tape.

2. **Damage code**. Record the appropriate damage code for each tree.
    a. Record a single damage code for each tree. If multiple damage codes apply to a tree, record the code that is highest on the following list:
        1. G: on **G**round; completely pushed over, uprooted, or snapped below 1.3m height
        2. S: **S**napped; stem snapped above 1.3 m height
        3. C: damaged **C**anopy; half or more of tree canopy damaged/killed
        4. B: damaged **B**ark; ≥ 100 cm^2 (10 x 10 cm) of bark damage due to impact of skidding equipment
        5. L: **L**eaning; tree leaning ≥ 10˚ from vertical due to impact of skidding equipment
            I. Note: do not include trees leaning due to natural causes.
    b. Example: if a tree is on ground (G), with significant canopy damage (C), and bark damage (B), record only G on the data sheet.

3. **Species**: Record species of tree if known. Scientific / Latin names are preferred. When Latin name is unknown, record the local name. If unknown, record "UNK".

4. **Commercial/Non-Commercial**. Record whether the tree is of a commercially valuable species or not.
    a. NOTE: Commercial tree species are those that are currently being harvested within a given concession. If possible, consult with concession workers to determine which species are currently being harvested.

- ## Part 5. Biomass of Unlogged Forest

Go to the point selected on haul road adjacent to unlogged cutting block (see Part 1.3 above), and proceed with the following steps:

1. Determine the compass direction of a transect line that is perpendicular to the nearest ridge line.
2. Select a random starting point.
    a. Select the first two digits that are between 0 and 50 from the random number sheet.
    b. Add 100 to that number.
    c. Proceed that distance in meters along the transect compass bearing.
3. Put a stake in the ground at the location reached to mark the first biomass plot location
4. Record a GPS waypoint, coding waypoint with a leading "B".
    a. Record biomass plot number, Latitude and Longitude on the datasheet.
5. Measure % slope in the uphill and downhill direction from plot center. Average the two measurements together and record as Slope of Land.
6. Verify the Basal Area Factors (BAFs) to be used for the biomass sampling and record the BAF on the datasheet.
    a. The standard approach is to use a 2 BAF for the small BAF and a 4 BAF for the large BAF.
    b. Ideally, this will select ~12 trees with the small BAF and ~12 trees with the large BAF.
    c. If sampling consistently returns more or fewer sample trees, the BAFs used may be adjusted in consultation with the project manager.
    d. The same two BAFs must be used at all biomass plots for a given site.
7. Start facing due north and proceed in a clockwise direction, using the large BAF angle gauge to identify all trees ≥ 10 cm (not including lianas) which are "in". For each "in" tree, measure/record:
    a. **Diameter** to nearest 0.1 cm. If a buttress exists, record diameter above the buttress.
        i. Refer to the Supplementary Figures for additional details on unusual tree diameters.
    b. **Species**: Record species of tree if known. Scientific / Latin names are preferred. When Latin name is unknown, record the local name. If unknown, record "UNK".
    c. **Commercial/Non-Commercial**. Record whether the tree is of a commercially valuable species or not.
        i. NOTE: Commercial tree species are those that are currently being harvested within a given concession. If possible, consult with concession workers to determine which species are currently being harvested.
    d. **Total tree height**. For only the first tree selected, measure height from the base of the tree to the highest living portion of the tree.
        i. Record height to the nearest 0.1 m.
        ii. If the tree is leaning more than 5° from vertical, make sure to measure height from a location where you can view the tree perpendicular to the direction of the lean.

8. Record the number of trees identified as "In" using the smaller BAF angle gauge.
    a. Thoroughly search the area around plot center, to ensure the person using the angle gauge can see all stems that might possibly be "in". It is easy to miss trees due to thick vegetation, but this non-detection must be avoided at all costs. This is the most important measurement collected in the entire protocol.
    b. **NOTE**: if it is difficult to visually determine whether a given tree is "in" or "out", use the limiting distance tables to positively determine whether the tree should be sampled.
        i. Measure the dbh of the questionable tree to the nearest 1 cm.
        ii. Lookup the limiting distance for that dbh in the limiting distance table for the appropriate BAF.
        iii. Measure the horizontal distance from the center of the tree to plot center, to the nearest 0.1 m.
        iv. If the limiting distance ≥ measured distance: the tree is "in", measure it. If the limiting distance < measured distance: the tree is "out", don't measure it.
9. Document the plot with digital photos.
    a. First, take a photo of the datasheet, to help identify plot photos later.
    b. Then take a photo at roughly breast height facing north, then south.
10. Proceed 100 meters in the transect direction to the next point, and repeat measurements.
11. Once the boundary of the cutting block is reached (or if you reach the edge of a recently logged area), proceed 100 meters deeper into the unlogged cutting block parallel to compass direction of ridge line, and begin a new transect, heading back towards ridge line.
12. Complete at least **15 biomass plots** within each concession.

DOCUMENT HISTORY

Version	Date	Changes
v1.0	dd mmm 2025	Initial version released