Verified Carbon Standard

VCS Module

VMD0063

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

Version 1.0

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Sectoral Scope 14: Forestry and Other Land Use

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CONTENTS

1 SUMMARY DESCRIPTION 4

2 SOURCES 4

3 DEFINITIONS 5

4 APPLICABILITY CONDITIONS 6

5 PROCEDURES 8

5.1 GHG Emission Reductions from Improved Felling Practices 9

5.2 GHG Emission Reductions from Improved Skidding Practices 10

5.3 GHG Emission Reductions from Improved Hauling Practices 11

6 DATA AND PARAMETERS 13

6.1 Data and Parameters Available at Validation 13

6.2 Data and Parameters Monitored 17

6.3 Monitoring Plan 24

7 REFERENCES 25

APPENDIX 1: RIL-C REGIONAL FORESTRY BEST PRACTICES STAKEHOLDER WORKSHOP 27

APPENDIX 2: DERIVATION OF IMPACT PARAMETER CREDITING BASELINES AND ADDITIONALITY BENCHMARKS 31

APPENDIX 2: LIKELIHOOD OF MORTALITY ARISING FROM VARIOUS TYPES OF DAMAGE TO TREES 37

APPENDIX 3: FIELD METHODS: CARBON EMISSIONS FROM LOGGING OPERATIONS IN THE REPUBLIC OF CONGO 39

1 SUMMARY DESCRIPTION

This module is used in conjunction with VCS methodology *VM0035 Methodology for Improved Forest Management through Reduced Impact Logging*, to account for GHG emission reductions (reductions) resulting from implementation of reduced impact logging (RIL-C) practices in natural forests in northern Republic of the Congo.

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 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. After this they will be reassessed and the module will be updated.

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

- Poor training and adoption of directional felling practices that often result in a 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[1]
- Use of unplanned yarding areas along skid trails and haul roads

2 SOURCES

This module is used in conjunction with *VM0035*. It is based on 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*.

[1] Evenly spaced, consistently branching skid trail networks with few loops and parallel paths decrease skidding damage and emissions.

3 DEFINITIONS

Actual harvest area (A_t)
Forest area that is actually accessed by haul roads and skidding equipment in year *t* (parameter A_t in *VM0035*).[2] In the context of this module, actual harvest area is the total area of harvest blocks (also known as parcelles) being harvested using RIL-C practices.

Annual harvest area
Total area authorized for harvest in a given year under a concession's operating license with the government, commonly referred to as assiette annuelle de coupe. Annual harvest area is inclusive of actual harvest area and also includes areas that are not harvested due to logistical or other constraints.

Collaterally damaged tree
Tree that has been accidentally damaged as a direct result of logging activities (e.g., damage from a skidder or from impact from a felled timber tree)

Concession
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 trees). Felled trees include trees that are felled and skidded from the actual harvest area to be transported to a mill, as well as trees that are felled but not skidded. Felled trees are identifiable by the presence of a chainsaw-cut stump of commercial size, or a commercially valuable log that has not been removed from the actual harvest area.

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

Harvest block
A designated sub-unit within the annual harvest area, which is frequently referenced in a concession's annual harvest planning. Harvest blocks are typically 25- or 50-hectare areas, square or rectangular in shape, and oriented to cardinal directions.

[2] Authorized area of harvest may be larger than actual harvest area due to inclusion of unstocked areas or areas where timber harvest and skidding are infeasible (e.g., due to geographic features), or areas set aside from logging activity.

Hauling
Use of trucks or other road-bound vehicles to transport logs from a log landing or a roadside storage area to another location outside the actual harvest area, typically a sawmill or other processing facility. Hauling is typically the step immediately after skidding, but is a fully separate process in the context of this module.

Logging landscape
The geography, class of actors or 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 with a diameter of at least one third of the diameter of the main stem from which it emerges

Merchantable log
Any section of a felled tree which is sufficiently straight to allow milling, and where the outside bark diameter is at least 30 cm. Logs with central hollow sections or cracks are considered merchantable in the context of this module, as the emissions from those portions of waste may be avoided by selecting alternative harvest trees and/or avoiding damage during felling.

Skidding
Activities to move a log from the location where it landed after tree felling, to a location where it may be loaded on a truck, typically either a log landing or the roadside. This includes two activities that are commonly distinguished in the Republic of the Congo: “debusquage” and “debardage.”

4 APPLICABILITY CONDITIONS

This module is applicable under the following conditions:

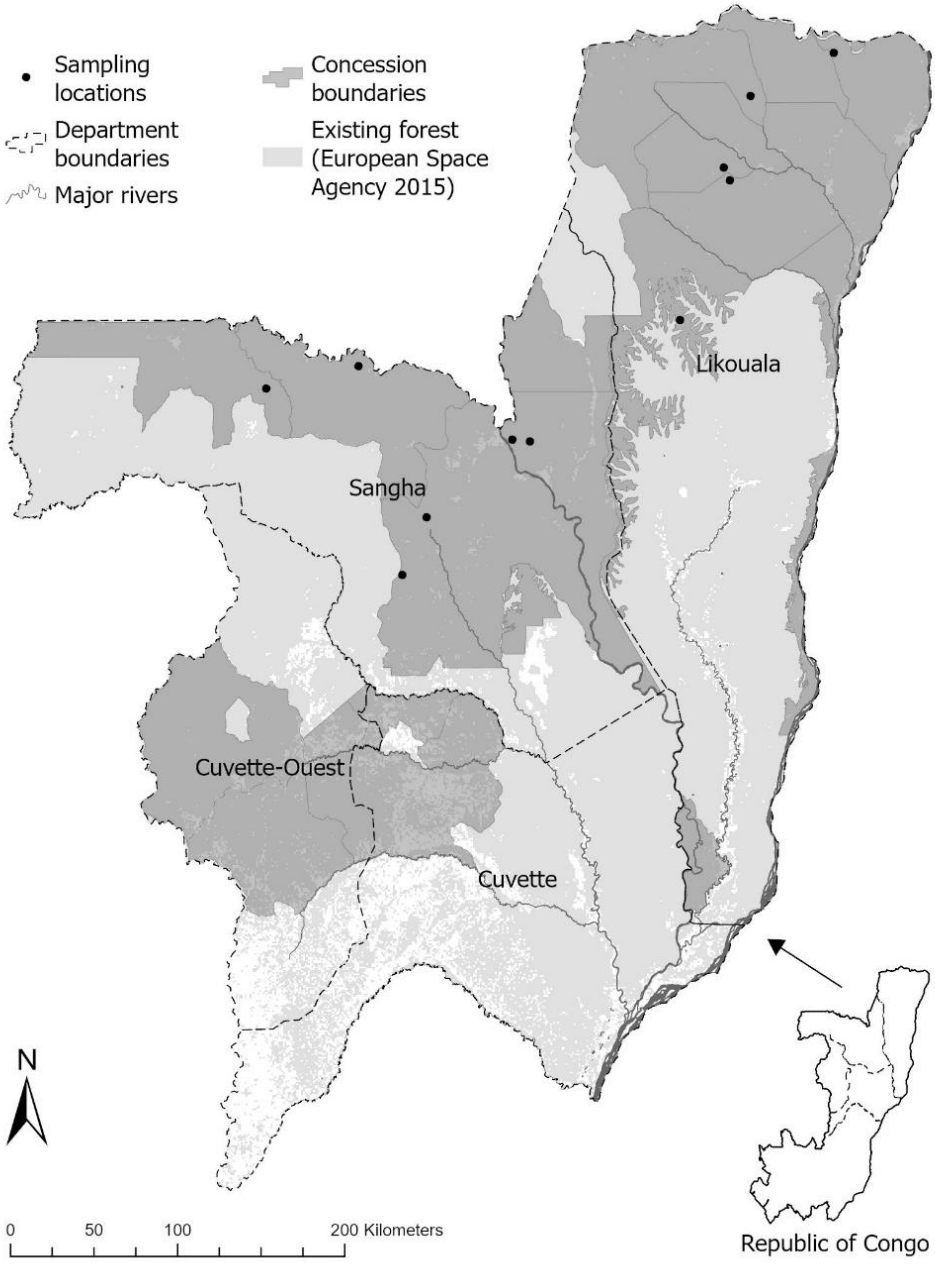
1) The project is located in the logging landscape in the northern Republic of the Congo shown in Figure 1, in a forest concession designated by the Republic of the Congo government in the department of Congo-Oubangui, Cuvette, Cuvette-Ouest, Likouala, and Sangha.

2) The project area is within a concession where logging occurs with proper government authorization.

3) The project area is within the boundaries established by a ,government-approved Forest Management Plan (FMP).

4) Logging is 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).

Figure 1. Logging landscape in the northern Republic of the Congo, within which this module is applicable (logging landscape depicted in dark gray)



This module is not applicable under the following conditions:

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

2) Felled tree density (FTD_t) is below 0.25 trees/ha (as measured at the annual harvest block level).[3]

5 PROCEDURES

GHG emissions from felling, skidding, and hauling are estimated based on the following impact parameters:

- Average number of trees with DBH > 10 cm that are damaged per felled tree (FELL1) (number of trees)
- Average proportion of felled logs that are abandoned in the forest following harvest (FELL2) (%)
- Average number of trees with DBH ≥ 20 cm that are damaged by skidding per harvest area (SKID) (trees/ha)
- Area of haul road and log landing corridors per unit of harvest area (HAUL) (m^2/ha)

The crediting baseline and additionality benchmark for each impact parameter is given in Table 1. Background information on the selection of performance benchmarks and crediting baselines is given in Appendix 2.

This module specifies the crediting baseline value of each impact parameter with subscript B (e.g., FELL1B) and the value measured in the project in year t with subscript M,t (e.g., FELL1M,t); together they represent the generic FELLt, SKIDt, and HAULt notation used in VM0035 Equations 1–6.

Table 1. Crediting baseline and additionality benchmark of each impact parameter

Impact parameter	Unit	Crediting baseline	Additionality benchmark
FELL1	number of trees	7.2	5.9
FELL2	%	6.1	5.5
SKID	trees/ha	3.3	2.6
HAUL	m^2/ha	404.3	330.8

[3] 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). Where harvesting occurs below this threshold, it is assumed that harvest levels have been deliberately reduced.

5.1 GHG Emission Reductions from Improved Felling Practices

Reductions resulting from lowering the average number of trees with DBH > 10 cm that are damaged per felled tree (FELL1) are estimated using Equation (1). FELL1 encompasses both f_{AGC} and f_{BGB} as referenced in *VM0035*.

$$ER_{FELL1,t} = (FELL1_B - FELL1_{M,t}) \times CDB_{FELL1} \times FTD_t \times 44/12 \quad (1)$$

Where:

$ER_{FELL1,t}$	=	Total reductions due to changes in the number of collaterally damaged trees within the actual harvest area at time *t* (t CO_2e/ha)
$FELL1_B$	=	Crediting baseline for average number of trees with DBH > 10 cm that are damaged per felled tree (number of trees)
$FELL1_{M,t}$	=	Average number of trees with DBH > 10 cm that are damaged per felled tree in the project in year *t* (number of trees)[4]
CDB_{FELL1}		Carbon emitted from collateral damage caused to one tree during felling operations (t C/collaterally damaged tree)
FTD_t	=	Felled tree density in the actual harvest area at time *t* (trees/ha)
44/12	=	Ratio of molecular weight of carbon dioxide to carbon (dimensionless)

Reductions resulting from lowering the proportion of felled logs that are abandoned in the forest following harvest (FELL2) are estimated using Equation (2). FELL2 encompasses both f_{AGC} and f_{BGB} as referenced in *VM0035*.

$$ER_{FELL2,t} = (FELL2_B - FELL2_{M,t}) \times FLB_{FELL2} \times 44/12 \quad (2)$$

Where:

$ER_{FELL2,t}$	=	Total reductions due to changes in the proportion of felled logs abandoned in the forest after harvest in the actual harvest area at time *t* (t CO_2e/ha)
$FELL2_B$	=	Crediting baseline for average proportion of felled logs abandoned in the forest after harvesting (%)[5]

[4] $FELL1_{M,t}$ together with $FELL2_{M,t}$, corresponds to the generic felling impact parameter $FELL_t$ referenced in VM0035 Equations 1 and 4. In this module, $FELL1_{M,t}$ and $FELL1_B$ (crediting baseline) are used instead of the separate fAGC and fBGB functions in VM0035, with emissions from aboveground and belowground carbon included in the term CDBFELL1.

[5] $FELL2_{M,t}$ together with $FELL1_{M,t}$, corresponds to the generic felling impact parameter $FELL_t$ referenced in VM0035 Equations 1 and 4. In this module, $FELL2_{M,t}$ and $FELL2_B$ (crediting baseline) are used instead of the separate fAGC and fBGB functions in VM0035, with emissions from aboveground and belowground carbon included in the term FLBFELL2

$FELL2_{M,t}$ = Average proportion of felled logs abandoned in the forest after harvesting in the project at time *t* (%)

FLB_{FELL2} = Mean carbon emitted from felled trees that are not completely extracted from the forest (t C/ha)

44/12 = Ratio of molecular weight of carbon dioxide to carbon (dimensionless)

5.2 GHG Emission Reductions from Improved Skidding Practices

Reductions resulting from decreasing the number of trees greater than or equal to 20 cm DBH that are damaged by skidding operations per hectare of harvest area are estimated using Equation (3).

$$ER_{SKID,t} = (SKID_B - SKID_{M,t}) \times CDB_{SKID} \times 44/12 \quad (3)$$

Where:

$ER_{SKID,t}$ = Total reductions due to changes in the number of trees greater than or equal to 20 cm DBH that are damaged by skidding operations in the actual harvest area at time *t* (t CO_2e/ha)

$SKID_B$ = Crediting baseline for mean number of trees greater than or equal to 20 cm DBH damaged by skidding operations (trees/ha)

$SKID_{M,t}$ = Mean number of trees greater than or equal to 20 cm DBH damaged by skidding operations in the project at time *t* (trees/ha)[6]

CDB_{SKID} = Carbon emitted from collateral damage to one tree during skidding operations (t C/collaterally damaged tree)

44/12 = Ratio of molecular weight of carbon dioxide to carbon (dimensionless)

The mean number of trees greater than or equal to 20 cm DBH damaged by skidding operations in the project at time *t* ($SKID_{M,t}$) is estimated using Equation (4).

$$SKID_{M,t} = SKID_{dens,t} \times SKID_{dam,t} \quad (4)$$

Where:

$SKID_{M,t}$ = Mean number of trees greater than or equal to 20 cm DBH damaged by skidding operations in the project at time *t* (trees/ha)

$SKID_{dens,t}$ = Average length of skid trails in actual harvest area at time *t* (m/ha)

[6] $SKID_{M,t}$ corresponds to the generic skidding impact parameter $SKID_t$ referenced in VM0035 Equations 2 and 5. In this module, $SKID_{M,t}$ and $SKID_B$ (crediting baseline) are used instead of the separate fAGC and fBGB functions in VM0035, with emissions from aboveground and belowground carbon included in the term CDBSKID

$SKID_{dam,t}$ = Average number of trees with DBH greater than or equal to 20 cm that are collaterally damaged per meter of skid trail in actual harvest area at time t (trees/m)

The average length of skid trails in the actual harvest area at time *t* ($SKID_{dens,t}$) is estimated using Equation (5).

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

Where:

$SKID_{dens,t}$ = Average length of skid trails in actual harvest area at time *t* (m/ha)

$L_{SKID,i,t}$ = Entire length of skid trail network in sampled harvest block *i* in actual harvest area at time *t* (m)

$A_{SKID,i,t}$ = Area of harvest block *i* sampled for skid trail length in actual harvest area at time *t* (ha)

n = Total number of sampled harvest blocks

The average number of trees with DBH greater than or equal to 20 cm that are collaterally damaged per meter of skid trail in the actual harvest area at time *t* ($SKID_{dam,t}$) is estimated by weighting the skid trail network length using Equation (6).

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

Where:

$SKID_{dam,t}$ = Average number of trees with DBH greater than or equal to 20 cm that are collaterally damaged per meter of skid trail in actual harvest area at time *t* (trees/m)

$L_{SKID,i,t}$ = Entire length of skid trail network in sampled harvest block *i* in actual harvest area at time *t* (m)

$Tree_{dam,i,t}$ = Number of collaterally damaged trees with DBH greater than or equal to 20 cm per skid trail in sampled harvest block *i* in actual harvest area at time *t* (number of trees)

n = Total number of sampled harvest blocks

5.3 GHG Emission Reductions from Improved Hauling Practices

Reductions resulting from decreasing the area of haul road and log landing corridors are estimated using Equation (7). For consistency and conservativeness, it is assumed that the haul road and log landing emissions attributable to a given annual harvest area are those from clearing haul road and log landing corridors within the boundaries of the annual harvest area.

$$ER_{HAUL,t} = \left(HAUL_B - HAUL_{M,t}\right) \times 0.0001 \times FB_{Unlogged} \times 44/12 \quad (7)$$

Where:

$ER_{HAUL,t}$	=	Total reductions due to changes in the area of haul road and log landing corridors at time *t* (t CO_2e/ha)
$HAUL_B$	=	Crediting baseline for area of haul road and log landing corridors (m^2/ha)
$HAUL_{M,t}$	=	Area of haul road and log landing corridors in the actual harvest area in the project at time *t* (m^2/ha)[7]
$FB_{Unlogged}$	=	Forest biomass carbon prior to clearing for construction of haul road and log landing corridors, minus roundwood extracted (t C/ha)
44/12	=	Ratio of molecular weight of carbon dioxide to carbon (dimensionless)
0.0001	=	Conversion factor from m^2 to ha (dimensionless)

The area of haul road and log landing corridors in the actual harvest area in the project at time *t* ($HAUL_{M,t}$) is estimated using Equation (8). 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 are considered. Log landings (or yards) are located alongside haul roads and represent a second separate element of this impact parameter.

$$HAUL_{M,t} = RA + LA \quad (8)$$

Where:

$HAUL_{M,t}$	=	Area of haul road and log landing corridors in the actual harvest area in the project at time *t* (m^2/ha)
RA	=	Average area of cleared forest haul roads per hectare of actual harvest area (m^2/ha)
LA	=	Average area of cleared log landing corridors per hectare of actual harvest area; equal to zero where no log landings are used (m^2/ha)

The average area of cleared forest haul roads (*RA*) is estimated from a census of haul road length and sampled widths of road corridor using Equation (9).

$$RA = \frac{L_{HR} \times \overline{W_{RC}}}{A_t} \quad (9)$$

[7] $HAUL_{M,t}$ corresponds to the generic hauling impact parameter $HAUL_t$ referenced in VM0035 Equations 3 and 6. In this module, $HAUL_{M,t}$ and $HAUL_B$ (crediting baseline) are used instead of the separate fAGC and fBGB functions in VM0035, with emissions from aboveground and belowground carbon included in the term FBUnlogged.

Where:

RA	=	Average area of cleared forest haul roads per hectare of actual harvest area (m^2/ha)
L_{HR}	=	Total length of forest haul roads in actual harvest area (m)
$\overline{W_{RC}}$	=	Average width of haul road corridors (m)
A_t	=	Actual harvest area (ha)

Average log landing corridor area (LA) is calculated from a monitored sample of log landing areas using Equation (10).

$$LA = \frac{\sum A_{LY}}{AS_{LY}} \quad (10)$$

Where:

LA	=	Average area of cleared log landing corridors per hectare of actual harvest area; equal to zero where no log landings are used (m^2/ha)
A_{LY}	=	Area of monitored log landing corridors (m^2)
AS_{LY}	=	Area sampled for log landing corridors (ha)

6 DATA AND PARAMETERS

6.1 Data and Parameters Available at Validation

Data/Parameter	$FELL1_B$
Data unit	number of trees
Description	Crediting baseline for average number of trees with DBH > 10 cm that are damaged per felled tree
Equations	(1)
Source of data	Default value derived from field data collected in 2019 and February–May 2022 across 11 sample sites in 9 concessions
Value applied	7.2
Justification of choice of data or description of measurement methods and procedures applied	The protocol for the collection of data that produced the default value is provided in Appendix 3, Part 4, Section B.
Purpose of data	Calculation of emission reductions
Comments	Derivation of the default value is described in detail in Appendix 2.

Data/Parameter	CDB_{FELL1}
Data unit	t C/collaterally damaged tree
Description	Carbon emitted from collateral damage caused to one tree during felling operations
Equations	(1)
Source of data	Default value derived from field data collected in 2022
Value applied	0.2326
Justification of choice of data or description of measurement methods and procedures applied	A conservative default value was calculated as the bottom end of the 95% confidence intervals based on measurements collected in northern Congo in 2022.
Purpose of data	Calculation of emission reductions
Comments	None

Data/Parameter	$FELL2_B$
Data unit	%
Description	Crediting baseline for average proportion of felled logs abandoned in the forest after harvesting
Equations	(2)
Source of data	Default value derived from field data collected in February–May 2022 across eight concessions
Value applied	6.1
Justification of choice of data or description of measurement methods and procedures applied	The protocol for the collection of data that produced the default value is provided in Appendix 3, Part 4, Sections A and B.
Purpose of data	Calculation of emission reductions
Comments	Derivation of the default value is described in detail in Appendix 2.

Data/Parameter	FLB_{FELL2}
Data unit	t C/ha
Description	Mean carbon emitted from felled trees that are not completely extracted from the forest

Equations	(2)
Source of data	Default value derived from field data collected in 2022
Value applied	2.721
Justification of choice of data or description of measurement methods and procedures applied	A conservative default value was calculated as the bottom end of the 95% confidence intervals based on measurements collected in northern Congo in 2022.
Purpose of data	Calculation of emission reductions
Comments	None

Data/Parameter	$SKID_B$
Data unit	trees/ha
Description	Crediting baseline for mean number of trees greater than or equal to 20 cm DBH damaged by skidding operations
Equations	(3)
Source of data	Default value derived from field data collected in 2019 and February–May 2022 across 11 sample sites at 9 concessions.
Value applied	3.3
Justification of choice of data or description of measurement methods and procedures applied	The protocol for the collection of data that produced the default value is provided in Appendix 3, Part 3, Sections A & B.
Purpose of Data	Calculation of emission reductions
Comments	Derivation of the default value is described in detail in Appendix 2.

Data/Parameter	CDB_{SKID}
Data unit	t C/collaterally damaged tree
Description	Carbon emitted from collateral damage to one tree during skidding operations
Equations	(3)
Source of data	Default value derived from field data collected in 2022
Value applied	0.31

Justification of choice of data or description of measurement methods and procedures applied	A conservative default value was calculated as the bottom end of the 95% confidence intervals based on measurements collected in northern Congo in 2022.
Purpose of data	Calculation of emission reductions
Comments	None

Data/Parameter	$HAUL_B$
Data unit	m^2/ha
Description	Crediting baseline for area of haul road and log landing corridors
Equations	(7)
Source of data	Default value derived from field data collected in 2019 and February–May 2022 across 11 sample sites in 8 concessions.
Value applied	404.3
Justification of choice of data or description of measurement methods and procedures applied	The protocol for the collection of data that produced the default value is provided in Appendix 3, Part 2, Sections A, B, & C.
Purpose of data	Calculation of emission reductions
Comments	Derivation of the default value is described in detail in Appendix 2.

Data/Parameter	$FB_{Unlogged}$
Data unit	t C/ha
Description	Forest biomass carbon prior to clearing for construction of haul road and log landing corridors, minus roundwood extracted
Equations	(7)
Source of data	Default value derived from field data collected in 2022
Value applied	167.2
Justification of choice of data or description of measurement methods and procedures applied	A conservative default value was calculated as the mean forest carbon in unlogged forests of the region, based on measurements collected in northern Congo in 2022.
Purpose of data	Calculation of emission reductions
Comments	None

6.2 Data and Parameters Monitored

Data/Parameter	$FELL1_{M,t}$
Data unit	number of trees
Description	Average number of trees with DBH > 10 cm that are damaged per felled tree in the project in year *t*
Equations	(1)
Source of data	Field surveys
Description of measurement methods and procedures to be applied	At least 100 felled trees must be sampled within at least two non-adjacent (i.e., not sharing any boundary) harvest blocks in the actual harvest area. All collaterally damaged trees per sampled felled tree are counted and used to calculate the average. Counts are conducted in all, or a subsample of, the same skid trail networks sampled for $L_{SKID,i,t}$ and $A_{SKID,i,t}$. Where a count of felled trees in a skid trail network is started, it must be completed.
Frequency of monitoring/recording	Within five years after completion of harvest in the actual harvest area
QA/QC procedures to be applied	Standard quality control / quality assurance procedures for forest inventory including field data collection and data management must be applied. A sampling plan and standard operating procedures (SOPs) for field measurements must be documented. Procedures to randomize selection of skid trail networks for sampling must be documented. Throughout field measurement events, an opportunistic sample of approximately 10% of sampled felled trees must be re-measured by different personnel to assess measurement error. The average difference in collaterally damaged tree count between re-measurements and original measurements must not exceed 10% of $FELL1_{M,t}$.
Purpose of data	Calculation of emission reductions
Calculation method	Divide number of trees collaterally damaged through felling by the number of felled trees which were sampled for collateral damage.
Comments	All felled trees felled within each harvest block in the most recent harvest must be recorded. A thorough search of the area should be made, including walking all areas within 20 m of skid trails. From this record, the sample of at least 100 felled trees is selected.

Data/Parameter	FTD_t
Data unit	trees/ha
Description	Felled tree density in the actual harvest area at time *t*

Equations	(1)
Source of data	Field measurements
Description of measurement methods and procedures to be applied	Complete census of the actual harvest area
Frequency of monitoring/recording	Within five years after completion of harvest in the actual harvest area
QA/QC procedures to be applied	Standard quality control / quality assurance procedures for forest inventory including field data collection and data management must be applied. Standard operating procedures (SOPs) for field measurements must be documented.
Purpose of data	Calculation of emission reductions
Calculation method	Calculated based on the commercial timber inventory conducted prior to each annual harvest
Comments	Includes any abandoned trees

Data/Parameter	$FELL2_{M,t}$
Data unit	%
Description	Average proportion of felled logs abandoned in the forest after harvesting in the project at time *t*
Equations	(2)
Source of data	Field surveys
Description of measurement methods and procedures to be applied	At least 100 felled trees must be sampled within at least two non-adjacent harvest blocks in the actual harvest area. These may be the same trees as those sampled for $FELL1_{M,t}$. Log length abandoned per sampled felled tree is recorded and used to calculate the average. Counts are conducted in all, or a subsample of, the same skid trail networks sampled for $L_{SKID,i,t}$ and $A_{SKID,i,t}$. Where a count of felled trees in a skid trail network is started, it must be completed.
Frequency of monitoring/recording	Within five years after completion of harvest in the actual harvest area
QA/QC procedures to be applied	Standard quality control / quality assurance procedures for forest inventory including field data collection and data management must be applied. A sampling plan and standard operating procedures (SOPs) for field measurements must be documented. Procedures to randomize selection of skid trail networks for sampling must be documented.

	Throughout field measurement events, an opportunistic sample of approximately 10% of sampled felled trees must be re-measured by different personnel to assess measurement error. The average difference in the proportion of felled trees abandoned between original measurement and re-measurement must not exceed 10% of $FELL2_{M,t}$.
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	A thorough search of the area should be made, including walking all areas within 20 m of skid trails.

Data/Parameter	$A_{SKID,i,t}$
Data unit	hectares
Description	Area of harvest block *i* sampled for skid trail length in annual harvest area at time *t*
Equations	(5)
Source of data	Geographic information system (GIS) analysis
Description of measurement methods and procedures to be applied	The area of the harvest block must be calculated using GIS layers from the concession's mapping operations and must reflect the entire area of a harvest block or "parcelle."
Frequency of monitoring/recording	Within five years after completion of harvest in the actual harvest area
QA/QC procedures to be applied	All GIS procedures applied to generate $A_{SKID,i,t}$ must be documented. Any imagery or GIS datasets used must be geo-referenced by corner points, clear landmarks, or other intersection points.
Purpose of data	Calculation of emission reductions
Calculation method	N/A
Comments	None

Data/Parameter	$L_{SKID,i,t}$
Data unit	meters
Description	Entire length of skid trail network in sampled harvest block *i* in actual harvest area at time *t*
Equations	(5), (6)
Source of data	Field surveys

Description of measurement methods and procedures to be applied	Measured directly by complete census of all skid trails within the selected sample blocks. Selected sample blocks must be non-adjacent. The census must include an exhaustive search within each selected sample block, including visual confirmation of lack of skid trails in any portion of the selected harvest block that is considered to be unlogged. The total skid trail length measured across all sampled harvest blocks must be at least 5 km.
Frequency of monitoring/recording	Within five years after completion of harvest in the actual harvest area
QA/QC procedures to be applied	Standard quality control / quality assurance procedures for forest inventory including field data collection and data management must be applied. A sampling plan and standard operating procedures (SOPs) for field measurements must be documented and specify how tracks unrelated to skid trail centerlines will be excluded from measurement. GPS accuracy during field measurements must be recorded and must be 10 m or more accurate. GIS smoothing procedures should be employed to eliminate GPS tracking error, which can cause raw GPS tracks to show small scale jagged lines that do not reflect actual skid trail centerlines.
Purpose of data	Calculation of emission reductions
Calculation method	N/A
Comments	Skid trails could start at any point within a harvest block.

Data/Parameter	$Tree_{dam,i,t}$
Data unit	number of trees
Description	Number of collaterally damaged trees with DBH greater than or equal to 20 cm per skid trail in sampled harvest block *i* in actual harvest area at time *t*
Equations	(6)
Source of data	Field surveys along censused skid trail networks
Description of measurement methods and procedures to be applied	Collaterally damaged trees are censused along the same skid trail networks measured to assess skid trail length ($L_{SKID,i,t}$). All collaterally damaged trees ≥ 20 cm DBH are counted. Collaterally damaged trees are those that have fallen to the ground, been uprooted, or have the trunk snapped below the first branch. Felled trees are not included in the count.
Frequency of monitoring/recording	Within five years after completion of harvest in the actual harvest area
QA/QC procedures to be applied	Standard quality control / quality assurance procedures for forest inventory including field data collection and data management must be

	applied. A sampling plan and standard operating procedures (SOPs) for field measurements must be documented. During field measurement, one sampled skid trail network must be re-measured for $Tree_{dam,i,t}$ and $L_{SKID,i,t}$ by different personnel to assess measurement error. $SKID_{dam,t}$ must be calculated independently using the re-measured parameters and Equation (6). The recalculated value must not differ by more than 10% from the initially measured value.
Purpose of data	Calculation of emission reductions
Calculation method	N/A
Comments	Any tree with DBH greater than or equal to 20 cm that has been indirectly damaged due to skidding activity is included in the count (e.g., a tree ≥20 cm DBH that was knocked down by a tree that was knocked down by a forestry tractor).

Data/Parameter	L_{HR}
Data unit	m
Description	Total length of forest haul roads in actual harvest area
Equations	(9)
Source of data	GIS maps and/or remote imagery (no coarser than 30 m resolution)
Description of measurement methods and procedures to be applied	The entire annual harvest block(s) must be fully censused for haul road length in year *t* using satellite imagery. Measurement of lengths must follow haul road centerlines. A complete census of all roads in the Actual Harvest Area is used to determine the length of haul roads and is monitored using GIS maps and/or remote imagery (with maximum 30 m resolution) with which road centerlines can be delineated and total haul road length measured, thus mapping haul road network accessing the Actual Harvest Area. GPS tracks of the centreline of each haul road within the Actual Harvest Area shall be collected to map the complete haul road network and measure total haul road length. Alternatively, remote sensing or GIS data may be used to directly map a census of haul road length within the actual harvest area.
Frequency of monitoring/recording	Within five years after completion of harvest in the actual harvest area
QA/QC procedures to be applied	Care should be taken to avoid GIS polylines that duplicate individual road segments, which can be especially prevalent at haul road intersections.
Purpose of data	Calculation of emission reductions

Calculation method	Sum all individual lengths of haul road segments within the Actual Harvest Area.
Comments	Each of the above monitoring measurements must focus exclusively on haul roads and log yards that were used as part of the harvest immediately preceding the verification period, i.e. the harvest which constitutes the project activity and for which the monitoring is being conducted. These measurements must not include haul roads or log yards developed for previous harvest events, unless they were re-cleared and used as part of the most recent harvest.

Data/Parameter	$\overline{W_{RC}}$
Data unit	m
Description	Average width of haul road corridors
Equations	(9)
Source of data	Field surveys
Description of measurement methods and procedures to be applied	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 the trunk of standing trees on either side of the road. Each road corridor width measurement must be collected perpendicular to the sampled road's centerline and must measure the distance from the near edge of the nearest tree bole on one side of the road corridor to near edge of the 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. A random or systematic (with random starting location) sample of 30 road corridor width measurements (where the corridor is measured as the width between the nearest standing tree trunk on either side of the road) distributed across not less than 5.0 km of road length 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 near edge of the nearest tree bole on one side of the road corridor to near edge of the 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. 30 separate width measurements must be collected within the Actual Harvest Area, distributed systematically across not less than 5 km of haul road length.

Frequency of monitoring/recording	Within five years after completion of harvest in the Actual Harvest Area.
QA/QC procedures to be applied	Project proponents and validation/verification bodies (VVBs) must check that width measurements have been taken based on a correct interpretation of road corridor width (i.e., perpendicular to the road centerline and from the near edge of the nearest tree bole on one side of the road corridor to the near edge of the nearest tree bole on the other side of the road corridor). Standard quality control / quality assurance procedures for forest inventory including field data collection and data management must be applied. A sampling plan and standard operating procedures (SOPs) for field measurements must be documented. Procedures to randomize selection of road corridor width measurements for sampling must be documented. During field measurement events, an opportunistic sample of approximately 10% of sampled road corridor widths must be re-measured by different personnel to assess measurement error. The average difference in corridor width between re-measurements and original measurements must not exceed 10% of $HAUL_{M,t}$.
Purpose of data	Calculation of emission reductions
Calculation method	Average of all road corridor widths by summing the individual measurements and dividing by the number of samples.
Comments	Each of the above monitoring measurements must focus exclusively on haul roads and log yards that were used as part of the harvest immediately preceding the verification period, i.e. the harvest which constitutes the project activity and for which the monitoring is being conducted. These measurements must not include haul roads or log yards developed for previous harvest events, unless they were re-cleared and used as part of the most recent harvest.

Data/Parameter	A_{LY}
Data unit	m^2
Description	Area of monitored log landing corridors
Equations	(10)
Source of data	Field surveys
Description of measurement methods and procedures to be applied	Log landings should be censused within two harvest blocks of the actual harvest area and mapped either with GPS units in the field or GIS analysis with high resolution (≤2m resolution) remote sensing layers. Using a handheld GPS unit with area measurement functionality, circumnavigate the outer edge of each sampled log landing, walking from tree trunk to tree trunk along the forested edge of the log landing

	corridor and along the edge of the haul road on the roadside edge of the log landing corridor. Field monitoring crews should search systematically to find all log landing corridors within the harvest blocks being sampled.
Frequency of monitoring/recording	Within five years after completion of harvest in the Actual Harvest Area.
QA/QC procedures to be applied	Project proponents and VVBs should ensure that log landing areas have been measured from the edge of adjacent haul roads to the nearest tree trunk in every direction, ensuring that measurements have not been incorrectly taken to the dripline of trees.
Purpose of data	Calculation of emission reductions
Calculation method	N/A
Comments	Measurements should only include log landing corridors that were used as part of the harvest immediately preceding the verification period (i.e., the harvest that constitutes the project activity and for which the monitoring is being conducted). Log landing corridors developed for previous harvest events should not be included, unless they were re-cleared and used as part of the most recent harvest.

Data/Parameter	AS_{LY}
Data unit	hectares
Description	Area sampled for log landing corridors
Equations	(10)
Source of data	GIS maps
Description of measurement methods and procedures to be applied	The area of the entire harvest block that has been sampled for log landing corridors as part of monitoring.
Frequency of monitoring/recording	Within five years after completion of harvest in the actual harvest area
QA/QC procedures to be applied	Ensure that the area reflects the total area of all the sampled harvest blocks.
Purpose of data	Calculation of emission reductions
Calculation method	Sum of the total area of all harvest blocks that were sampled for log landing corridors.
Comments	None

6.3 Monitoring Plan

The purpose of monitoring is to generate primary data after harvesting is completed in the actual harvest area, to describe impacts of harvest on the residual stand from which GHG emission reductions can be estimated. Primary data may include a combination of field and remote measurements. Following completion of timber harvesting in the actual harvest area, all parameters in Section 6.2 must be sampled to generate primary data, and calculations using the equations in this module must use primary data.

Monitoring RIL-C impact parameters in the logging landscape of northern Congo involves the following:

- Accessing the actual harvest area
- Georeferencing and/or mapping skid trails, haul roads, and log landing corridors
- Sampling skid trails for number of collaterally damaged trees
- Sampling the width of haul roads and the size of log landing corridors
- Sampling felled trees for collateral damage and log abandonment

Throughout the project crediting period, monitoring must be conducted within five years after each harvest. However, given the rapid regrowth potential of forests in the Republic of the Congo and that monitoring data are required for verification, monitoring within 1–2 years after harvest is recommended. Monitoring more than two years after harvest is likely to increase the time and expense of monitoring.

7 REFERENCES

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

Republique du Congo



Unité – Travail – Progrès



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 comprising 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.

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 (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 raised 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 timber 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 2.

Table 2: 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

LAST NAME First Name	Institutions
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: 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 (Table 3 and Table 4 below).

All data presented are based on field measurements collected in 11 selected annual harvest blocks across nine concessions in the northern Republic of the Congo, all located within the specified logging landscape (Figure 1). Eleven sites were selected using two stratified random samples. Three of the sites were originally selected as part of a global assessment of RIL-C mitigation potential by Ellis et al. (2019). The remaining eight were selected using a similarly stratified probability proportional to size (PPS) sample, which included all actively managed concessions in the northern Republic of the Congo and weighted concessions by total hectares within the legally designated concession. In both stratified random samples, sites were stratified according to whether the concession was certified by the Forest Stewardship Council (FSC) to ensure representation of both certified and non-certified concessions.

Each sampled site is represented by one forest management planning unit, each approximately 50 ha in total area, which was the location for detailed measurements of logging activity. These selections were necessarily more opportunistic than random, with appropriate selections defined as those where logging had been implemented within the preceding 12 months (to ensure field crew's ability to clearly detect stump locations, collaterally damaged trees, etc.), active logging was fully completed (to ensure safety of field crews), and there were at least 50 hectares of harvestable forest land (to ensure sufficient sampling of harvesting damage components). Selections were made in consultation with each concession's operations staff, with explicit request to select blocks for sampling that were in every notable way "typical."

The final sample of 11 harvest blocks included:

- Five harvest blocks in concessions that have current FSC certification, and six harvest blocks in concessions without FSC certification
- Three harvest blocks measured in 2019 as part of the Ellis et al. (2019) study, and eight harvest blocks measured in 2022 as part of the work explicitly intended to support this module
- Harvest blocks sited within nine of 13 distinct, actively managed concessions
- Harvest blocks controlled by eight of nine distinct concessionaires, who collectively control all actively managed concessions in the northern Republic of the 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 five 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 (Ellis et al. 2019; Umunay et al. 2019).[8] 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 module 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.

The following RIL-C practices have the potential to reduce carbon emissions from timber harvesting operations within the logging landscape:[9]

- Efficient planning and use of improved construction materials to reduce permanent forestry infrastructure (i.e., haul roads and log yards)
- Improved skid trail planning
- Commercialization of upper stem logs (i.e., those above the first major branch) and other wood waste
- Improved tracking of felled trees to avoid butt log abandonment (i.e., all felled trees are completely extracted and brought to a mill or other facility)
- Improved use of directional felling
- Improved utilization of buttressed butt logs

All crediting baselines were set at the mean value for each impact parameter, Additionality benchmarks were set at 40th percentile of the distribution of sampled values for each impact parameter. The values for all impact parameter benchmarks and the basis for their derivation, are given in Table 1 and Table 4. The option of using an additionality benchmark that is more conservative than the eventual crediting baseline was initially developed for the VM0035

[8] Includes data from three sites used in the present study.

[9] Based on the results of Umunay et al. (2019), operational limitations, and the output of a stakeholder workshop on 30 September 2022 (see Appendix 1)

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) rewards those operators who generate less collateral damage from forestry operations 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. Use of this lower additionality benchmark ensures that concessions are not credited for marginal improvements. This 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

Performance Benchmark Procedures

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-C practices. The biased inclusion of FSC certified concessions in the sample results in a conservative baseline, as explained above.

Table 3. 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 collaterally 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 (m^2 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 4. Calculation of baseline and additionality benchmarks

Harvest Block Code	Year Measured	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 (m^2 ha^{-1}).
ROC2	2019	8.2	unavailable	1.9	511.2
ROC5		16.0	unavailable	4.7	349.0
ROC6		9.6	unavailable	2.4	623.7
ROC7	2022	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

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. 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 collaterally damaged trees on logging sites in Peru, categorizing the collaterally damaged trees into one of five types of damage. Table 5 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 5.

Table 5: 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

For example, consider a simplified example: a tree with known biomass which is collaterally damaged by felling, with the resulting impact that the tree's stem is snapped below the first branch.

- The tree's aboveground biomass is 10 Mg and its belowground biomass if 2.35 Mg.
- Because the stem was snapped below the first branch, the (s) collateral damage type, and the associated emissions factors are relevant to this tree.

- This tree's emitted carbon is estimated as:

$$Carbon\ Emitted = 0.47 * \big((10Mg * 1.0) + (2.35Mg * 0.509)\big)$$

$$Carbon\ Emitted = 0.47 * \big((10Mg) + (1.196Mg)\big)$$

$$Carbon\ Emitted = 0.47 * (11.196Mg)$$

$$Carbon\ Emitted = 5.26MgC$$

- The tree's emitted carbon, 5.26MgC, is then pooled with others to calculate the total emissions due to collateral damage caused by the felling of the tree intended for harvest.
- Data from many felled trees are then pooled together to estimate the average emissions caused by collateral damage from felling a tree.

1) Finally, the average emissions caused by collateral damage from felling a tree is divided by the average number of trees collaterally damaged from felling a tree. That value is an estimate of the average emissions caused by each tree collaterally damaged by felling and directly accounts for the type of collateral damage felling typically causes (e.g. the proportion of trees with bark damage vs crown damage). This final value is used as the collateral damage biomass factor (CDBFELL1) which is fully described in the section headed "Appendix 2: Likelihood of mortality arising from various types of damage to trees".

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. This field protocol was used in the development of baseline impact parameter data for this and other modules, and it **is not intended as a protocol for collecting the monitoring data described in Section 6.2 of this module**. Rather, this protocol is provided for informational purposes and to give context for understanding the way the module has been developed.

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 eight concessions is suggested to obtain minimum standard of reliability of regional estimates. More samples are 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 comprises, at minimum, three 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 at using 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 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 three adjacent, recently closed cutting blocks for field measurements from among the current year's cutting blocks. From the three selected cutting blocks, randomly select one "focus sample". The focus sample is intended for sampling of all components, i.e. skid trails, felled trees, log yards, collateral damage, and haul road measurements. The remaining two 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 six 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 four waypoints directly in the GPS unit that form a roughly 50 ha area.
    i) For reference, a 50-ha subsample would be a 707 m x 707 m square.
- Whatever method you use, document the 50-ha subsample for later use. This location and its 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 100 meters (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, felled 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, provided they are consistent, efficient, documented, and easily interpreted.

Section A. GPS Data

1) **Point data:** Record GPS waypoints 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:** Record GPS line data (“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 centimeter (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 centimeter (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 one square meter (m^2) 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 three (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 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 felled 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.

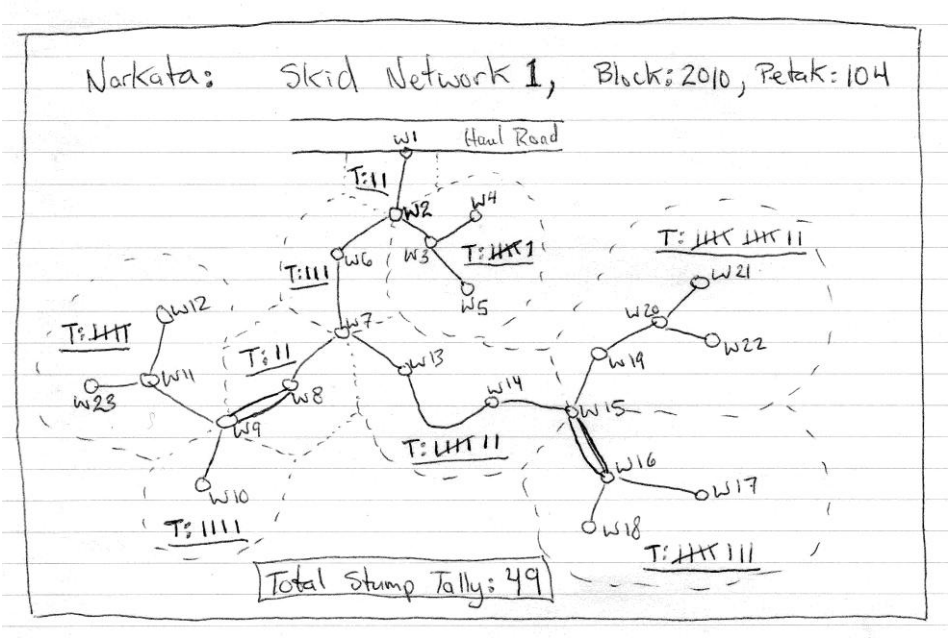


Figure 2: Example of skid trail network field diagram

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 felled 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.

- 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 centimeter – 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) Collaterally 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 five millimeters (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 collaterally 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. Felled tree Impacts

Felled 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. "Felled trees" include all trees felled with the intention of harvesting, including those trees for which no trunk section was actually removed from the forest. "Felled trees" do NOT include those trees that were only felled to access another tree, build a skid road, etc.

1) Determine first felled tree gap to sample:
    a) Randomly select a number 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 felled 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 felled 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 felled tree vs. another nearby felled tree, then sample all felled 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 felled trees have been sampled, continue sampling felled trees in the adjacent skid trail network, until at least 15 have been sampled.
    b) If 15 felled trees are sampled before the entire skid network has been sampled, continue sampling every 5th stump up to a maximum of 20 sampled felled trees.

c) If 20 felled trees are sampled, the remainder of the skid network may be left unsampled.

d) Thus, a total of 15-20 felled trees should be sampled per concession, within selected cutting block.

Section A. Felled-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-tree sample, including each felled 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 felled 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 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 centimeter (0.1 m).

    b) Measure stump diameter(s) at the top of the stump, i.e. the point where the tree was cut, to the nearest centimeter (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 millimeter (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 millimeter (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 centimeter (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 millimeter (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 centimeter (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 felled tree(s), record the following information:

1) Diameter at breast height (DBH): Measure diameter of the stump or log to the nearest millimeter (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:

        i) G: on Ground; completely pushed over, uprooted, or snapped below 1.3 m height

        ii) S: Snapped; stem snapped above 1.3 m height

        iii) C: damaged Canopy; half or more of tree canopy damaged/killed

        iv) B: damaged Bark; ≥ 100 cm^2 (10 cm x 10 cm) of bark damage due to impact of skidding equipment

        v) L: Leaning; tree leaning ≥ 10˚ from vertical due to impact of skidding equipment

            - 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 in this Appendix), 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 millimeter (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 centimeter (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 centimeter (0.1 m).

ii) Look up 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 centimeter (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	Comment
v1.0	4 November 2026	Initial version