Quantification Methodology Climate Change Mitigation from Silviculture Investments

Version 1.0

2026-01-27

Forest Analysis and Inventory Branch
Ministry of Forests

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Foreword

Although it is not a legislated requirement, B.C. Ministry of Forests quantifies greenhouse gas emissions attributed silviculture investments as a means of tracking climate action in BC's Forest Sector. The complexities that accompany quantification and communication of human-caused emissions from specific management activities demand a comprehensive, and standardized, approach. I approve this methodology as a step towards consistently, and transparently, measuring how silviculture programs contribute to overall climate change mitigation from B.C.'s forest sector.

Jan 23, 2026

Shane Berg, RPF — Date

Assistant Deputy Minister and Chief Forester

Ministry of Forests

1 Background and Purpose

Greenhouse gas (GHG) emissions are widely used as a measure of performance towards climate change mitigation. This document summarizes the methodology used to quantify the GHG impact resulting from silviculture investments in British Columbia's (BC's) forest sector.

The methodology is applicable to performance measurement for a broad portfolio of investment programs and policies (Lemprière et al., 2013). To support a wide range of information needs, the reporting framework is focused on describing the GHG impact of specific "action categories" across BC's public forest land, such as tree planting in areas affected by natural disturbance, forest nutrient management, and reducing damage caused by defoliator outbreaks.

The methodology supports subject literacy, policy assessments, funding decisions, and performance measurement through the BC Ministry of Forests Service Plan[1]. Outputs have supported prioritization of investments by funding programs, including Forests For Tomorrow (FFT), Forest Carbon Initiative (FCI), CleanBC, and Forest Investment Program (FIP). Finally, specific outputs have supported information requests from BC Ministry of Forests executive leadership and partner agencies, including the BC Forest Enhancement Society (FESBC), and BC Timber Sales (BCTS).

The publication of this document provides assurances that BC consistently follows a transparent and reproducible methodology that meets Open Government standards[2] and the open data and science standards of reputable scientific journals.

The methodology was first initiated in 2018 and has evolved according to continuous improvements in data collection, production of analysis ready datasets, technical computing resources, accounting policy, and analysis.

[1] https://www2.gov.bc.ca/gov/content/governments/organizational-structure/ministries-organizations/ministries/forests/service-plan

[2] https://www2.gov.bc.ca/gov/content/governments/about-the-bc-government/open-government

2 Disclaimer

While steps have been taken to align methods with those of national GHG inventories (NGHGIs)[3], provincial forest landscape modelling[4], project-level protocols[5], investment-level protocols[6], and community-level protocols[7], some methods are uniquely tailored towards the goals of the BC Ministry of Forests. These goals include supporting subject literacy, comprehensive and detailed performance measurement of specific investments, and timely adoption of advancements in scientific research and information management. According to a continuous improvement plan, the standard and the implementation thereof are subject to annual review and potential update of:

- Primary data
- Analysis ready datasets
- Model functions
- Model parameters
- Accounting inclusion criteria
- Accounting inclusion status of biophysical processes, funding sources, and action categories.

The most recent annual release replaces previous releases as the official source of estimates. This methodology document will be periodically updated as needed.

[3] https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html

[4] https://intranet.gov.bc.ca/assets/intranet/flnrord/frad/forest-landscape-plans/forest-landscape-models-standards-guidance.pdf?

[5] https://www2.gov.bc.ca/gov/content/environment/climate-change/industry/offset-projects/offset-protocols

[6] https://ww2.arb.ca.gov/our-work/programs/california-climate-investments

[7] https://ghgprotocol.org/gpc-supplemental-guidance-forests-and-trees

3 Information Management

Estimation methods were supported by a technical computing framework that linked data, code, analysis, and delivered products (Figure 1). Primary data were available from the BC Data Catalogue[8]. Secondary data[9] included province-wide geospatial databases and supporting spreadsheets. Georeferenced modelling was based on data from a 1-hectare (ha) raster database (BC1HA). Supporting spreadsheets included geospatial lookup-tables (LUTs), literature reviews, spreadsheet databases that summarized numerical evidence, and workbooks (i.e., spreadsheet 'calculators') serving to prepare, test, and evaluate methods for specific model processes. Supporting spreadsheets were made publicly available through BCBox[10].

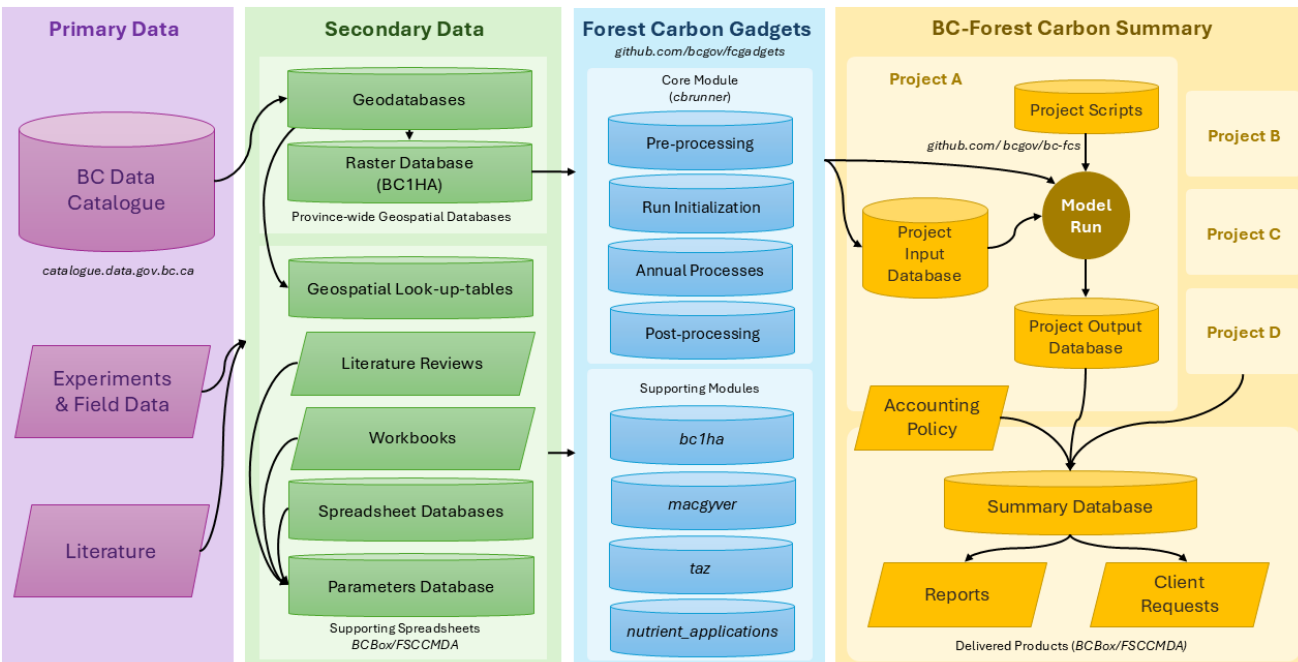

Figure 1. Schematic description of technical computing framework.

Code was stored in repositories (folders) and modules (files ending in ".*py*") (Table 1). Modules contained two types of code: Functions and scripts (Figure 2). Functions are self-contained building blocks of code designed to perform a specific task or calculation. A script is a set of instructions that routinely call on functions to execute a specific task (e.g., annual database update or model run). Functions were stored in a repository

[8] https://catalogue.data.gov.bc.ca/

[9] Data that has been derived from primary data through reformatting, reorganization, aggregation, disaggregation, compilation, or compaction

[10] https://bcbox.nrs.gov.bc.ca/list/objects?bucketId=e6349313-ba58-42f2-8b9b-ede6d3deec6e

called Forest Carbon Gadgets (*fcgadgets*)[11]. The scripts were stored in a repository called the BC Forest Carbon Summary (*bc-fcs*)[12].

Written in the Python 3 programming language, the *fcgadgets* repository contains modules from various published studies and code repositories, culminating in a 'plug-and-play' computing environment. The *fcgadgets* repository included a core repository called *cbrunner* (see Section 5.1 through 5.5), and supporting repositories that provided general utilities, or accommodated specialization in estimation of biophysical processes for specific types of modelling projects (see Section 5.6). The *fcgadgets* repository also housed the *bc1ha* repository, which maintained functions that oversaw automated production and update of the BC1HA database (see Section 4).

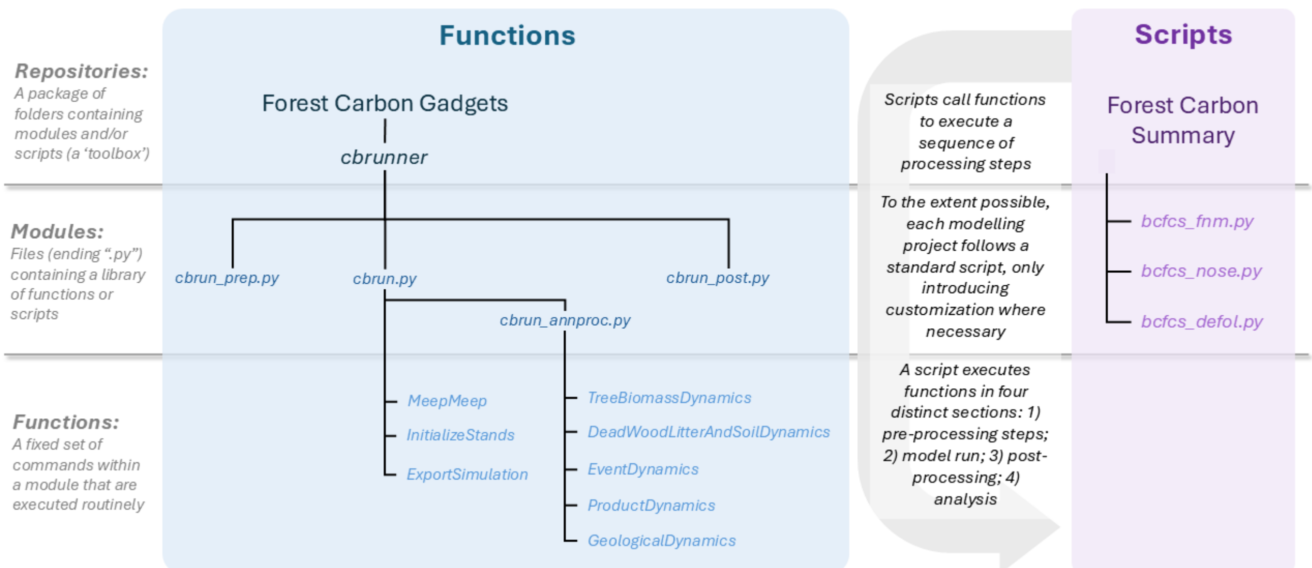

Figure 2. Organizational structure of modelling projects using Forest Carbon Gadgets.

Individual modelling projects and summary information was organized within an umbrella project called the BC Forest Carbon Summary (BC-FCS). Each modelling project was driven by scripts stored in the *bc-fcs* repository. A frozen copy of inputs and outputs for various modelling projects were posted to BCBox (Table 2). The output from each modelling project was stored in a Summary Database[13]. Modelling projects belonging to BC-FCS consistently adopted a standard set of analysis ready datasets (see Section 4), estimation methods (Section 5), attribution methods (Section 6), and accounting methods (Section 7).

[11] https://github.com/RobbieHember/fcgadgets

[12] https://github.com/bcgov/bc-fcs

[13] https://bcbox.nrs.gov.bc.ca/list/objects?bucketId=e6349313-ba58-42f2-8b9b-ede6d3deec6e

Table 1. List of important modules called by users in the execution of modelling project scripts. Handle refers to the shortform given to modules upon loading into the Python computing environment.

Repository	Sub-repository	Module	Code content	Handle
fcgadgets	*bc1ha*	*bc1ha_utils.py*	Functions	*u1ha*
fcgadgets	*bc1ha*	*bc1ha_com.py*	Script	N.A.
fcgadgets	*cbrunner*	*cbrun.py*	Functions	*cbr*
fcgadgets	*cbrunner*	*cbrun_annproc.py*	Functions	*annproc*
fcgadgets	*cbrunner*	*cbrun_util.py*	Functions	*cbu*
fcgadgets	*cbrunner*	*cbrun_preprocess.py*	Functions	*prep*
fcgadgets	*cbrunner*	*cbrun_postprocess.py*	Functions	*post*
fcgadgets	*macgyver*	*until_fnm.py*	Functions	*unm*
fcgadgets	*macgyver*	*until_nose.py*	Functions	*unose*
fcgadgets	*macgyver*	*until_general.py*	Functions	*gu*
fcgadgets	*macgyver*	*until_gis.py*	Functions	*gis*
fcgadgets	*hardhat*	*economics.py*	Functions	*econ*
fcgadgets	*hardhat*	*nutrient_applications.py*	Functions	*napp*
fcgadgets	*taz*	*default_stat_event_sim.py*	Functions	*dses*
bc-fcs	*scripts*	*bcfcs_fnm.py*	Script	N.A.
bc-fcs	*scripts*	*bcfcs_nose.py*	Script	N.A.

Table 2. Frozen copies of input and output files for modelling projects. NOSE: Non-obligation stand establishment; FNM: Forest nutrient management; DM: defoliator mitigation; MPB: Mountain Pine Beetle (*Dendroctonus ponderosae*); Btk: *Bacillus thuringiensis* kurstaki.

Action Category	Project Code	Project Name	Description
NOSE	Demo_Ref_Underplant	Underplanting demonstration	Single-stand demonstrations of climate change mitigation from underplanting for coastal and interior regions
NOSE	Demo_Ref_SalvageMPB	Salvage harvest demonstration	Single-stand demonstrations of climate change mitigation from salvage harvesting in MPB-impacted stands for interior region
NOSE	BCFCS_NOSE	Provincial summary of non-obligation stand establishment	Provincial summary of climate change mitigation from non-obligation stand establishment
FNM	Demo_FNM	Forest nutrient management demonstration	Single-stand demonstrations of climate change mitigation from forest nutrient management for coastal and interior regions

FNM	BCFCS_FNM	Provincial summary of forest nutrient management	Provincial summary of climate change mitigation from forest nutrient management
DM	Demo_DM_HemlockLooper	Protection against hemlock looper demonstration	Single-stand demonstrations of climate change mitigation from BTK spray of stands impacted by hemlock looper
DM	BCFCS_DM	Provincial summary of defoliator mitigation	Provincial summary of climate change mitigation from BTK spray of stands impacted by hemlock looper and western spruce budworm

4 Data Sources

Modelling relied on observations of current forest conditions, natural disturbance events, harvesting and other forest management activities. This section summarizes how those data were drawn from BC Government information systems and used in climate change mitigation analysis.

4.1 Geospatial Databases

Information about forest management activities from the previous year was entered into government systems by March 31st. At that time, data layers were downloaded from BC Data Catalogue[14]. Using functions from the utilities module, *bc1ha_utils.py*, the variables were rasterized and standardized within a continuous, regular 1 ha grid with the Albers projection system (BC1HA). All files were stored as compressed geotiffs with 8-, 16- or 32-bit integer precision. All categorical variables were encoded according to establishing lists LUTs that provided a crosswalk between the numerical ID in the geotiff file and the categorical codes and descriptions. Supporting functions were written so that operators needed only to reference categorical codes. As categorical variables changed frequently (i.e., introduction of new codes), the LUTs were reconstructed on an annual basis.

Table 3. List of primary geospatial data sources.

Layer name	Description
BEC_BIOGEOCLIMATIC_POLY [Link]	Biogeoclimatic zone and subzone
PROT_HISTORICAL_FIRE_POLYS_SP [Link]	Historical wildfire perimeters and year
PEST_INFESTATION_POLY [Link]	Historical insect outbreak perimeters, severity class, and year
RSLT_OPENING_SVW [Link]	Forest management activities
RSLT_ACTIVITY_TREATMENT_SVW [Link, Data Dictionary]	Forest management activities, funding source, and year
RSLT_PLANTING_SVW [Link]	Planting species, seedlot and planting density
VEG_COMP_LYR_R1_POLY [Link]	Species composition, stand density, stand age
VEG_CONSOLIDATED_CUT_BLOCKS_SP [Link]	Harvest perimeters and year
VEG_BURN_SEVERITY_SP [Link]	Burn severity rating

4.2 Analysis Ready Datasets

The development of analysis ready datasets (ARDs) from the raw data files employed the following processes:

- Derivation of new variables based on a compilation of multiple raw input variables: LUTs for derived variables were generated manually as spreadsheets (see *Parameters* folder).
- Gap-filling: Some variables with gaps were modified to fill gaps (see Section 5.2.5).

[14] https://catalogue.data.gov.bc.ca/

- Reduction of redundancy: To reduce file read/write time by an order of magnitude, annual geotiffs were compacted into a reduced number (typically 4 to 12) of layers. Scripts were used to uncompact them.

These ARDs covered event types, including natural disturbances, harvest and other forest management activities. Common event types are listed below.

4.2.1 Wildfire

A wildfire compilation was generated from the information from PROT_HISTORICAL_FIRE_POLYS_SP layer. For each compacted layer, the database tracked:

- Year
- Day of year
- Burn severity rating

Burn severity rating was supplied by the VEG_BURN_SEVERITY_SP layer. Records of wildfire occurrence began in 1920, while burn severity began in 2015. Instances of DISTURBANCE_CODE = “B” in RSLT_ACTIVITY_TREATMENT_SVW were added to the wildfire compilation. See Table 3 for link to data dictionary. Burn severity was gap-filled (see Table 7).

4.2.2 Insect Outbreaks

A compilation of insect outbreak occurrence was generated from the aerial overview survey (PEST_INFESTATION_POLY). Combinations of insect code and mortality were encoded with the crosswalk found in *Parameters_InsectComp1.xlsx*. Mortality was derived from severity class (Maclauchlan et al., 2025; Westfall and Duthie-Holt, 2021). For each compacted occurrence, the raster database tracked:

- Year
- Insect code / mortality combination ID

Outbreaks were recorded for 1950 to present.

4.2.3 Harvesting

Harvest information was compiled from the VEG_CONSOLIDATED_CUT_BLOCKS_SP layer. Instances of DISTURBANCE_CODE = “L” or “S” in RSLT_ACTIVITY_TREATMENT_SVW were added to the harvest compilation. Day of year was unavailable for harvest so it was assumed, by default, that harvest occurs on day 1 of the year with recorded harvest. See Table 3 for link to data dictionary.

4.2.4 Stand Establishment

A provincial stand establishment compilation was updated each year based on information from the RSLT_ACTIVITY_TREATMENT_SVW layer of RESULTS. See Table 3 for link to data dictionary. For each stand establishment event, the database recorded:

- Year
- Day of year
- Species code 1 to 6
- Species percent 1 to 6
- Seedlot-weighted genetic worth (of volume yield)
- Planting density
- Funding source code
- Artificial stand establishment type (ASET)

Where attribute information was available, but no spatial information was found in the RSLT_ACTIVITY_TREATMENT_SVW layer, the function defaulted to the spatial boundary of the opening with STOCKING_TYPE_CODE = "ART" from the RSLT_FOREST_COVER_INV_SVW layer, as it was assumed this was a close indicator of where planting occurred. Where no "ART" areas could be found, the function defaulted to the boundary of the opening. If the resulting area exceeded ACTUAL_TREATMENT_AREA, a component of the area was removed at random to preserve ACTUAL_TREATMENT_AREA. Species ID, species percent and planting density were drawn from the RSLT_PLANTING_SVW layer. A complete list of seedlot ID and genetic worth was drawn from the *Parameters_Seedlot_GW.xlsx.*

To facilitate modelling and associated information requests, a classification system was developed to categorize artificial stand establishment events, including planting and direct seeding, into artificial stand establishment types (ASETs; Table 4). The classification system drew on silviculture technique and method codes from the RESULTS activity layer, obligation status (*Parameters_ByFSC.xlsx*), and preceding disturbance events. The classification system was tailored to meet specific information requests and complexities in accounting and reporting. There are several known limitations in the ASET compilation, particularly going back in time. Some degree of misclassification is expected due to challenges in alignment of the information collected.

Table 4. List of artificial stand establishment types and brief description.

Name	Description
Harvest and Planting	Licensee operations with an obligation to reforest area. All instances after 1987 were classified as obligation stand establishment.
Harvest and Planting Non Satisfactorily Restocked (NSR) Backlog	Licensee harvesting that occurred prior to 1988 with planting funded by non-licensee funding sources.
Salvage and Planting Post Beetle	Salvage and planting following catastrophic mortality due to bark beetles. This was identified by planting events that were preceded by bark beetle occurrence with severity > "Trace".
Salvage and Planting Post Wildfire	Salvage and planting following catastrophic mortality due to wildfire. This type was identified by planting events that were preceded by occurrence of wildfire or some other natural disturbance.
Knockdown and Planting	Planting that was preceded by mechanical overstory removal.
Road Rehabilitation	Planting on roads.
Underplanting	Planting beneath a dead overstory. Prior to introduction of the "UNDER" code (found in RSLT_ACTIVITY_TREATMENT_SVW layer), this was identified by silviculture technique code = PL preceded by a wildfire.
Straight-to-planting Post Beetles	Planting beneath a dead overstory killed by bark beetles. This was identified by planting preceded by a beetle occurrence and no wildfire or harvest.
Straight-to-planting Post Other	Planting beneath a dead overstory. This was identified by planting preceded by a natural disturbance not including bark beetles or wildfire.
Back-to-back Planting	Planting following planting recorded in the preceding year. This is an artifact arising from imperfections in the spatial mapping of planting projects. It occurs when planting projects within the same opening are conducted across multiple years. The first of the two planting records is used in modelling, while the second instance is discarded.
Fill Planting	Identified from silviculture technique code = "FP" (RSLT_ACTIVITY_TREATMENT_SVW layer).
Replanting	Identified from silviculture technique code = "RP" (RSLT_ACTIVITY_TREATMENT_SVW layer).
Direct Seeding	Identified from silviculture base code = "DS" (RSLT_ACTIVITY_TREATMENT_SVW layer).

Ecosystem Restoration	This type consists of stand establishment in riparian areas, subalpine meadows, and areas impacted by landslides. Identified by SILV_OBJECTIVE_CODE_1 = "ER" or "HER" (RSLT_ACTIVITY_TREATMENT_SVW layer), or VEG_COMP_LYR_R1_POLY species ID 1 = "AT" or "ACT" or "PA".
Agroforestry and Short Rotation	Not in use.
Unknown	Failure of classification system to identify type of planting.

4.2.5 Aerial Nutrient Application

A provincial aerial nutrient application compilation was updated each year based on codes from the RSLT_ACTIVITY_TREATMENT_SVW layer of RESULTS. See Table 3 for link to data dictionary. Events were identified according to silviculture base code "FE" and silviculture technique code "CA." For each aerial nutrient application event, the database recorded:

- Year
- Day of year
- Funding source code

Each event was defined by a standard operational dose of urea equaling 200 kg N·ha^{-1} (Reid et al., 2017).

4.2.6 Knockdown

A compilation of knockdown (i.e., overstory removal without harvesting for fibre) was generated from RSLT_ACTIVITY_TREATMENT_SVW with silviculture base code of "SP" and silviculture method code of "CABLE", "GUARD", "HARV", "MDOWN", or "PUSH". See Table 3 for link to data dictionary. The compilation tracked:

- Year
- Day of year
- Funding source code

4.2.7 Slash Pile Burn

A compilation of slash pile burns was generated from RSLT_ACTIVITY_TREATMENT_SVW with silviculture base code of "SP", silviculture technique code "BU" and silviculture method code "PBURN". See Table 3 for link to data dictionary. The compilation tracked:

- Year
- Day of year
- Funding source code

5 Estimation

This section explains methods used to estimate carbon fluxes, changes in carbon pools over time, and GHG emissions resulting from all recognized biophysical processes.

5.1 General Overview

5.1.1 Boundary Conditions

The *cbrunner* repository tracked state variables and flux variables over multiple dimensions comprising of N_{Time} timesteps, N_{Stand} forest stands, $N_{Scenario}$ scenarios, and $N_{Ensemble}$ ensembles. These boundary conditions, along with all project-level parameters were specified by users in the *Project* tab of *ProjectConfig.xlsx* spreadsheet (see Section 5.9 for guidance on project setup and workflow).

The time period of the simulation was defined by t_{Start} and t_{End}. The input data and quality of estimates can vary with time, depending on when historical records became available, continuous improvements in data collection and information management standards, and finally with the transition from historical years to future years. The time period of simulations was, therefore, characterized by three distinct phases:

- Pre-observation period
- Observation period
- Future period

The start of the observation period was defined by the start date of the individual disturbance and management event data sources. The boundary between the observation and future period, $t_{Project}$, was normally set to the calendar year that the modelling project was conducted. This marked a shift in source of event information between observed records and on-the-fly simulations.

There were two spatial modes of operation; the spatial domain of a modelling project was set as:

- A single stand (N_{Stand} = 1), in which case all inputs were received from spreadsheets, or
- Multiple (georeferenced) stands (N_{Stand} >> 1), in which case spatially varying inputs were received from a raster database (BC1HA).

5.1.2 Scenarios & Scenario Comparisons

The model was designed to streamline scenario comparisons (i.e., comparing GHG emissions from multiple scenarios). For example, methods adopted here attribute GHG emissions to specific actions by comparing estimates of emissions from an “action” scenario with those from a “baseline” scenario (see Section 6 for further description of how scenarios are used in attribution). The land surface attributes (Section 5.2.4) did not vary among scenarios, but disturbance and management event chronologies (see Section 5.2.5) differed to address specific attribution objectives. Scenarios were designed by users in the “Scenario” tab of *ProjectConfig.xlsx* file.

5.1.3 Ensembles

The model accommodated probabilistic estimation by allowing multiple ensemble simulations ($N_{\text{Ensemble}} > 1$) with stochasticity in the simulation of event occurrences (e.g., future annual probability of wildfire), or uncertainty in parameter estimates. Deterministic simulations were performed by setting $N_{\text{Ensemble}} = 1$ and ensuring projection configuration excluded stochasticity.

5.1.4 State Variables

Total carbon was estimated from the sum of carbon stored in forest ecosystems, harvested wood products, and geological deposits (Figure 3). Forest ecosystem carbon pools followed those of Kurz et al. (2009) except for additional tracking of all tree components in dead wood and piles. Carbon pools within harvested wood products consisted of in-use products and waste systems (Dymond et al., 2016). Carbon pools within geological deposits consisted of coal, natural gas, oil and limestone. All state variables represented the end of the calendar year in tonnes of carbon ($tC \cdot h^{-1}$).

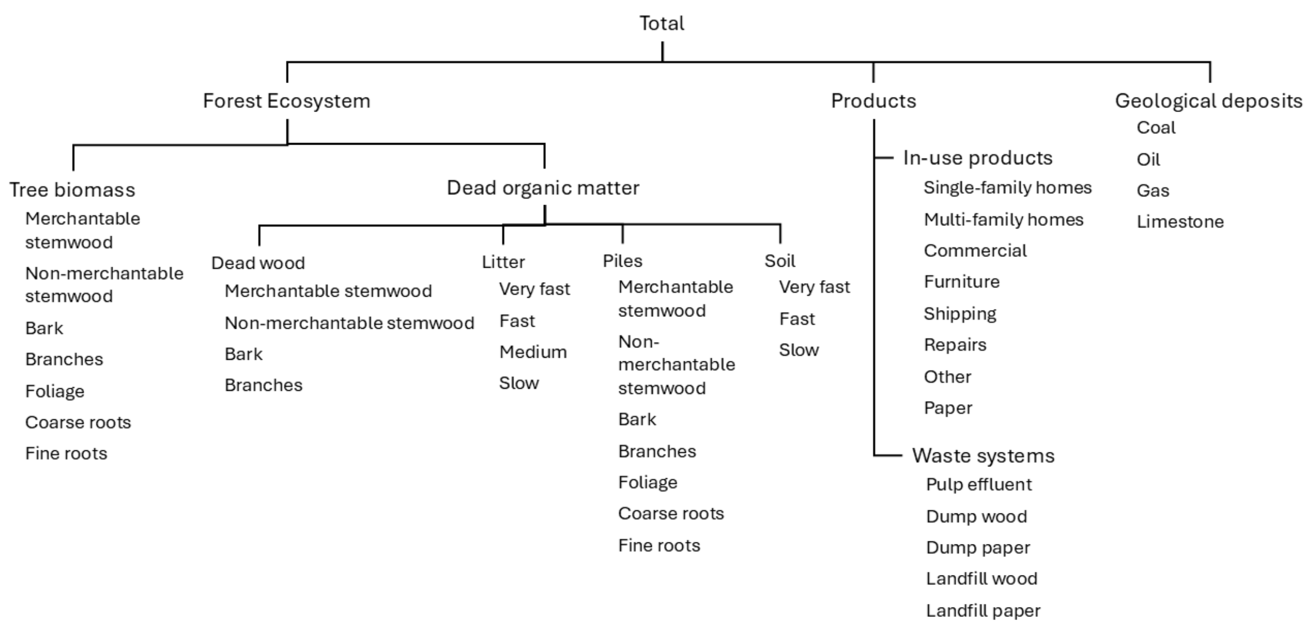

Figure 3. List of carbon pools.

5.1.5 Flux Variables

Annual GHG emissions (E) were estimated according to Eq. 1 (Table 5):

$$E = RH_{\text{Total}} + BB_{\text{Wildfire,Total}} + BB_{\text{Open Burning,Total}} + VOL_{\text{Total}} + DEN_{\text{Total}} + LR_{\text{Total}} + RH_{\text{Products}} + BB_{\text{Products}} + FF_{\text{Forestry Ops}} + FF_{\text{Substitutions}} + CP_{\text{Substitutions}} - NPP_{\text{Total}} - UCS \quad \text{(Eq. 1)}$$

Table 5. List of recognized GHG fluxes contributing to calculation of net GHG emissions. LULUCF: Land use, land use change and forestry.

Symbol	Description	Economic sector
RH_{Total}	Total heterotrophic respiration from forest ecosystems, calculated from the sum of domestic ($RH_{Domestic}$) and international ($RH_{International}$)	LULUCF-Forest
$BB_{Wildfire,Total}$	Total biomass burning from forest ecosystems due to wildfire, calculated from the sum of domestic ($BB_{Wildfire,Domestic}$) and international ($BB_{Wildfire,International}$)	LULUCF-Forest
$BB_{Open\ Burning,Total}$	Total biomass burning from forest ecosystems due to open burning (e.g., "pile burning" and "broadcast burning"), calculated from the sum of domestic ($BB_{Open\ Burning,\ Domestic}$) and international ($BB_{Open\ Burning,\ International}$)	LULUCF-Forest
VOL_{Total}	Total volatilization emissions from forest ecosystems after fertilization, calculated from the sum of domestic ($VOL_{Domestic}$) and international ($VOL_{International}$)	LULUCF-Forest
DEN_{Total}	Total denitrification emissions from forest ecosystems after fertilization, calculated from the sum of domestic ($DEN_{Domestic}$) and international ($DEN_{International}$)	LULUCF-Forest
LR_{Total}	Total lateral river transport from forest ecosystems (set to zero), calculated from the sum of domestic ($LR_{Domestic}$) and international ($LR_{International}$)	LULUCF-Forest
$RH_{Products}$	Heterotrophic respiration from decay of wood products	LULUCF-Forest
$BB_{Products}$	Biomass burning of wood products	LULUCF-Forest[15]
$FF_{Forestry\ Ops}$	Fossil fuel emissions associated with forestry operations (e.g., use of fuels to transport fertilizer)	Energy-Stationary Combustion and/or Energy-Transportation
$FF_{Substitutions}$	Displacement of fossil fuel emissions through use of wood products	Energy-Stationary Combustion and/or Energy-Transportation
$CP_{Substitutions}$	Displacement of cement production emissions through use of wood products	Industrial Products and Product Use
NPP_{Total}	Net primary productivity from forest ecosystems, calculated from the sum of domestic ($NPP_{Domestic}$) and international ($NPP_{International}$)	LULUCF-Forest

[15] Emissions of CH_4 can be reported in other economic sectors upon request.

UCS	Atmospheric carbon dioxide sequestration during production of urea.	Industrial Products and Product Use
E	Net GHG emissions	n.a.

Total forest ecosystem fluxes were defined by domestic and international components. Domestic fluxes dominated total fluxes. The model tracked international fluxes associated with traded raw log exports, manufactured solid wood products, and pellets. In principle, the model recognized the potential for leakage, which would be captured by international fluxes.

For each of the biophysical processes in Eq. 1, the model tracked fluxes of carbon dioxide (CO_2), methane (CH_4), carbon monoxide (CO), and nitrous oxide (N_2O). All emissions were combined to express carbon dioxide equivalent (CO_2e) emissions using the 100-year global warming potential values from Canada's NGHGI 2025[16]. For reporting, all fluxes were stratified by the economic sector listed in accordance with NGHGIs (Table 5).

5.2 Pre-processing

5.2.1 Project Configuration

To start a modelling project, users prepared the project- and scenario-specific parameters in the spreadsheet, *ProjectConfig.xlsx*.

5.2.2 Spatial Domain Definition

As part of the annual update and production of BC1HA, spatial binary masks for each modelling project were generated from the footprint of completed historical actions from each action category (e.g., stand establishment; Figure 4). The masks were automatically generated during the annual update with the *bc1ha_com.py* script.

[16] www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html

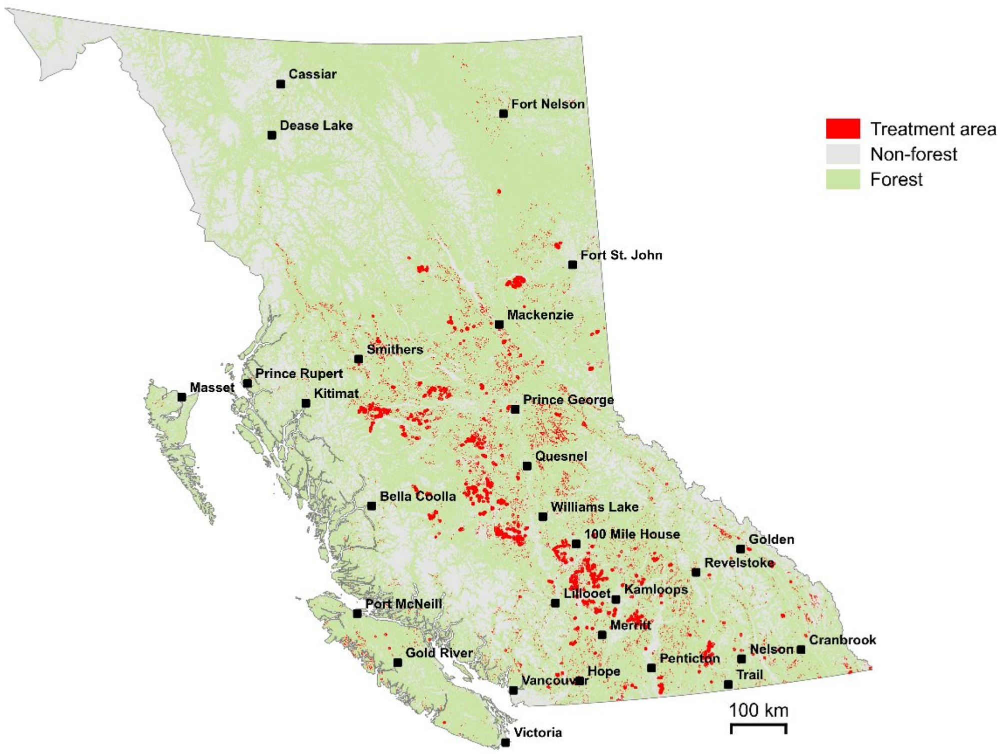

Figure 4. Example binary mask of non-obligation stand establishment with completed planting during 2024.

Computational challenges can arise from adopting a spatially-explicit approach to modelling. It was generally not necessary to conduct modelling at every 1 ha grid cell of the provincial layers of BC1HA. The system was designed to accommodate sparse sampling within the mask of the 1 ha grid. Users specified the regular grid sampling frequency (RGSF) for each project (set in the “Projects” tab of the *ProjectConfig.xlsx* file). The default setting was to conduct modelling at RGSF = 10 ha (i.e., conducting a model simulation at every tenth grid cell within the mask of the project).

With the binary mask and sampling frequency determined, users generated a set of sparse samples for each variable required for project modelling using *GenerateSparseInputs* from *bc1ha_utils.py*. This step reduced the computation time in pre-processing of modelling projects because, upon each subsequent execution of the model, the pre-processing steps only involved accessing the much-smaller sparse samples instead of the full provincial 1 ha datasets each time the model was run.

5.2.3 Geospatial Attributes (GEOS) File

The above pre-processing steps were part of the annual update process and were only executed once a year. Subsequent pre-processing steps for each modelling project were controlled by the *cbrun_preprocess.py* module. Every time the modelling project script was executed, the geospatial reference system, the binary mask, and the sparse sample coordinates were accessed from the sparse samples and stored in the GEOS file (*geos.pkl*) stored in the data folder of the modelling project.

5.2.4 Land Surface Attributes (LSAT) File

Variables with only one time element were drawn from the sparse sampling files and compiled within a LSAT file (*lsat.pkl*; Table 6). The LSAT file was a direct input to the model. Species composition of modelled stands was from the LSAT file (i.e., from the VRI) for all instances except the action scenario in non-obligation stand establishment following the focal stand establishment milestone[17]. In that exceptional case, the species composition was informed from the ASET compilation, as tracked in the disturbance and management event chronology (DMEC) file; see Section 5.2.5.

Table 6. List of variables stored in the land surface attribute (LSAT) file.

Name	Description
LC ID	Land cover from VEG_COMP_LYR_R1_POLY
BGC zone ID	Biogeoclimatic zone from BEC_BIOGEOCLIMATIC_POLY
Age	PROJ_AGE_1 from VEG_COMP_LYR_R1_POLY
Species IDs	Species 1 to 5 ID from VEG_COMP_LYR_R1_POLY
Species Percents	Species 1 to 5 percents from VEG_COMP_LYR_R1_POLY
MAT	Mean 1971-2000 annual temperature from ClimateNA (Wang et al., 2016)

5.2.5 Disturbance and Management Event Chronology (DMEC) File

Variables with multiple elements over time were compiled from the sparse input files and stored in a DMEC file (*dmec.pkl*). The DMEC file maintained a chronology of events for each stand and each scenario. For each event, variables included the year (and day of year where available), the type of event, and the impact of the event on tree growth and mortality. For each event, the DMEC tracks four additional variables that were crucial to attribution analysis:

1. An indicator for whether the event was represented in each scenario. Focal events were excluded from the baseline scenario and included in the action scenario following Project-specific Attribution Rules (PARs) specific to the action category and project type. The PARs dictate which events are included or excluded from each scenario and control potential growth curve transitions. They are built into the pre-processing functions (see *cbrun_preprocess.py*).
2. An indicator of obligation status for each event. Obligation status was defined by funding source code. See *Parameters_ByFSC.xlsx* for the crosswalk between Funding Source Code and Obligation Status.
3. An index to a preceding inciting event. For example, the inciting event in an Underplanting project is the preceding wildfire. In a Salvage Harvest and Planting project, the inciting event might be a bark beetle outbreak or a wildfire. This indicator was used to help manage the timing of growth curve transitions for each scenario.
4. An indicator of whether the event was generated directly from government information systems, or added based on gap-filling and alteration rules.

[17] The milestone that defines completion of the investment decision that we seek to attribute emissions to. It is included from the DMEC of the action scenario and excluded from the DMEC of the baseline scenario (see Section 6).

When future disturbance and management events were simulated on-the-fly, they were added to the DMEC and saved to file after executing the model (see Section 5.6.4). To varying degrees, gap-filling and alterations were applied to accommodate imperfections in field collection and information management of observations (Table 7).

Table 7. Event gap-filling assumptions.

Events	Gap-filling Assumptions
Aerial Nutrient Application	Areas that experienced aerial nutrient application periodically had no modern record of disturbance, yet it was known that the provincial program avoided treatment of old stands. Of the areas that experienced aerial nutrient application, and that had a recorded history of disturbances, analysis found that applications occurred, on average, at age 38 years, and typically following a harvest event. The event chronology for areas with no disturbance history were, therefore, gap-filled by adding a clearcut harvest 38 years prior to the nutrient application.
Salvage Harvest and Plant	No gap-filling or alterations to the historical record of salvage harvest events were performed.
Knockdown and Plant	No gap-filling or alterations to the historical record of knockdown events were performed.
Pile Burn	When salvage harvesting and knockdown events were not followed by a record of pile burn, it was assumed to be a false-negative error. Pile burn events were added with biogeoclimatic (BGC) zone-specific probabilities (see *Parameters_ByBGC.xlsx*).
Fill Planting and Replanting	The management of growth curves for the action and baseline scenarios depended on the identification of inciting events. Information systems did not track events that incited fill-planting and replanting. In all cases, a Drought event (with 100% mortality) was introduced in the year prior to record of a Fill Planting or Replanting event.
Underplanting	If no inciting wildfire or bark beetle event was detected prior to underplanting, a wildfire was added four years prior to the planting milestone. If burn severity of the inciting wildfire indicated mortality < 90%, the burn severity estimate was modified to equal 95% based on assurances from program staff that underplanting is consistently applied to stands with mortality exceeding 95%.

Road Rehabilitation	If no inciting road construction could be identified prior to road rehabilitation event, a deforestation (Forest to Transportation) event was added to the chronology 20 years prior to the planting milestone.

5.2.6 Growth Curves (GC) File

The pre-processing module contained a function, *Process2_PrepareGrowthCurves*, that automatically prepared growth curve files (*gc.pkl*) for use by each modelling project. The workflow was specific to spatial mode of operation. For non-georeferenced projects, the input parameters that drive *BatchTIPSY.exe* were populated by users in a spreadsheet, *GrowthCurvesTIPSY_Parameters.xlsx*. For georeferenced projects, the function automatically generated the growth curves from the sparse input files that were previously generated for the modelling project. Either way, the function generated a file, *GrowthCurvesTIPSY_InputVariables.dat*, which was formatted for the growth and yield model. Once the input parameters were prepared, users manually executed *BatchTIPSY.exe* by opening and running *GrowthCurvesTIPSY_Output.BTP*. Running *GrowthCurvesTIPSY_Output.BTP* generated output files, *GrowthCurvesTIPSY_Output.out*. In the final post-processing stage, users executed *Process3_PrepInputsByBatch* from the project script, which imported the Table Interpolation Program for Stand Yields (TIPSY) output file, reformatted the variables, and stored the data in *gc.pkl.*

BatchTIPSY.exe was run with the standard operational adjustment factors (OAF1 = 0.85, OAF2 = 0.95). Where planting information existed for the stand, initial density was defined by the planting density (i.e., number of trees planted divided by area treated), species composition was defined from the planting layer of RESULTS, and the model was run with the planted ("P") spatial distribution. Seedlot-weighted genetic worth was input (see *Parameters_Seedlot_GW_2025.xlsx*). Natural stand establishment followed biogeoclimatic (BGC) zone-specific initial stand densities that were estimated from analysis of field plots from the Change Monitoring Inventory (CMI) network (FAIB, 2018; Penner and Omule, 2012). Species composition defaulted to growth curve 1 (GC-1; species composition listed in the most recent VRI). Natural stands followed the natural ("N") spatial distribution. In consultation with surveyors, natural regeneration following wildfire in underplanting projects was defined by a stand establishment of 200 stems·ha^{-1} and a regeneration delay of 2 years.

Modelling projects adopted BGC zone-specific values of site index (SI). These values were tuned until modelled net growth of stemwood biomass was approximately equal to the average measurement of net stemwood biomass growth from the Young Stand Monitoring (YSM) field plot network (FAIB, 2018). For forest nutrient management, model estimates of net stemwood growth from the baseline scenario (not affected by nutrient applications) were compared against observations and the sample was confined to stands in the age range 28-48 (centered around the mean age at time of application). For non-obligation stand establishment, it was net stemwood growth from the action scenario (stand regeneration following planting) that was compared with observations and the sample was confined to the age range 10-60. This step ensured that modelling was driven by accurate estimates of net biomass growth.

The pre-processing steps established a set of (up to four) growth curves for each stand. In any given timestep, growth was defined by an "active" growth curve (GC-A). At the start of the simulation, the active growth curve was initially driven by GC-1, as defined by species composition in the VRI, a "natural" spatial distribution, zero genetic worth, and natural stand density. GC-1 was used over model spin-up and persisted until a management event triggered a transition of GC-A to growth curve two (GC-2), as defined by historical records of stand establishment, or future simulated events. This could be a natural stand (e.g., following natural disturbance), or a managed stand (e.g., following planting). If no harvest or planting event occurs, GC-A remained set to GC-1 through the full simulation.

In geospatial projects, a growth curve representing managed stands (GC-M) (i.e., with "planted" spatial distribution) was generated for each stand with *BatchTIPSY.exe* during pre-processing to accommodate stands that transition from the initial GC-1 to a second-growth (i.e., managed) stand. When a future (simulated) harvest event occurred, it was not accompanied by a historical (observed) record of stand establishment informing on how to parameterize *BatchTIPSY.exe*. In these instances, the active growth curve transitioned to GC-M, which was defined by the species composition from VRI and region-specific assumptions about genetic worth and planting density.

Table 8. Values of site index (m) at age 50 years used by modelling projects. Values were the result of a calibration against field observations of net growth of stemwood biomass.

Biogeoclimatic zone	Site Index (m) for Forest Nutrient Management	Site Index (m) for Non obligation Stand Establishment
BAFA	10.0	12.0
BG	12.0	14.4
BWBS	14.0	16.8
CDF	30.0	36.0
CMA	10.0	12.0
CWH	36.3	36.0
ESSF	20.2	22.1
ICH	26.8	28.6
IDF	16.0	20.0
MH	7.0	8.4
MS	15.0	20.3
PP	15.0	18.0
SBPS	12.0	18.0
SBS	22.4	23.8
SWB	12.0	14.4

5.3 Run Initialization

From the project script, users executed the function, *MeepMeep*. That function called:

1. *InitializeStands*, initializing all the state variables and flux variables and imported the LSAT, DMEC and GCs for each scenario and
2. *PrepareParameters*, populating the simulations with global parameters, scenario-specific parameters, parameters specific to region, BGC zone, or stand location, and parameters specific to time.

5.4 Annual Processes

Once the run was initiated, the model called a sequence of functions for each timestep in an annual loop between t_{Start} and t_{End}. These functions were stored within the *cbrun_annproc.py* module.

5.4.1 Regular Tree Biomass Dynamics

Forest biomass dynamics are driven by tree growth and a continuous spectrum in the frequency and intensity of stand-level tree mortality. In practice, the model stitched that continuous spectrum together from two sources: 1) Growth and Yield models that were responsible for simulating "regular" causes of tree mortality, and 2) event simulators that were responsible for simulating the occurrence and impact of "catastrophic" tree mortality (Figure 5).

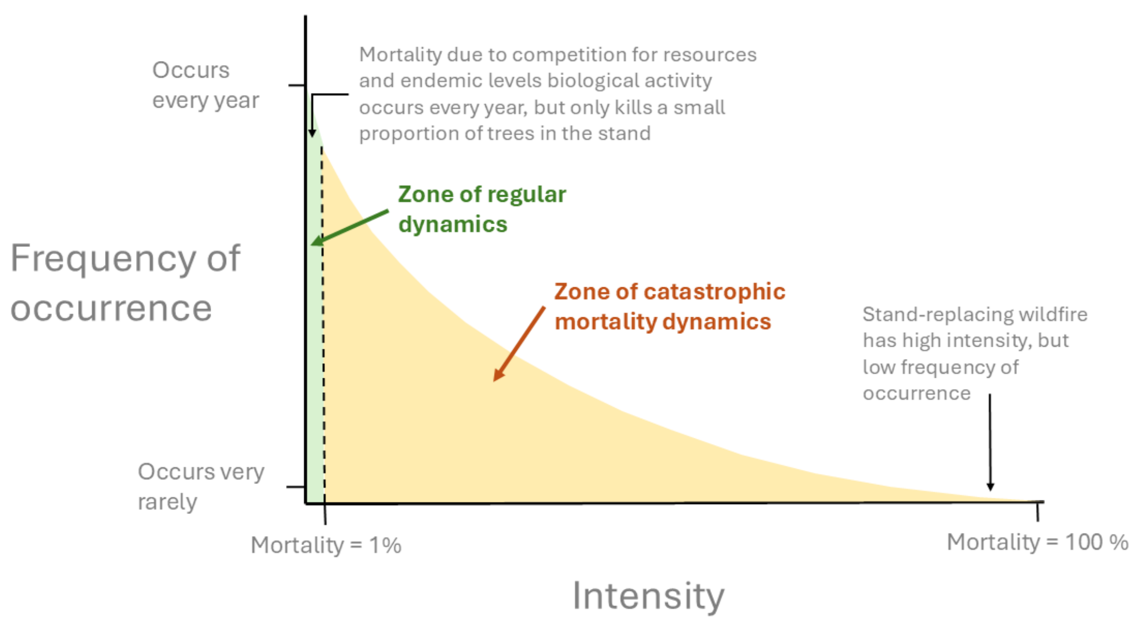

Figure 5. In the practice of empirical carbon modelling, tree mortality is represented by two separate yet equally important sources: The growth and yield models that predict regular rates of tree growth and mortality, and the event simulators that predict tree growth and mortality responses to catastrophic disturbance events.

The *TreeBiomassDynamicsFromGYModel* function estimated annual net primary productivity ($tCO_2 \cdot ha^{-1} \cdot yr^{-1}$) and end-of-year tree biomass carbon density ($tC \cdot ha^{-1}$) under regular conditions. The primary input to the function was net growth of stemwood biomass ($\Delta B_{Stemwood}$) predicted using the TIPSY growth and yield model

("Biomass Live Wood" from custom table, tC·ha^{-1})[18]. Prior to 2025, methods used *BatchTIPSY.exe* version 4.4 before switching to version 4.7 (planned in 2026 release).

Relationships between net growth of stemwood and net growth of each non-stemwood tissue (i.e., bark, branches, or foliage) were used to estimate net growth of each non-stemwood tissue. For example, net growth of bark was estimated from:

$$\Delta B_{\text{Bark}} = \Delta B_{\text{Stemwood}}(b_0 + [b_1 - b_0] \times \exp[b_2 \times A]) \quad \text{(Eq. 2)}$$

where $b_0 \ldots b_2$ were fitted coefficients describing the relationship between net growth of stemwood and net growth of bark, and A was stand age (adapted from Landsberg and Sands, 2011). Net growth of foliage and branches were estimated by fitting Eq. 2. The relationships were fitted against field plots belonging to the CMI and YSM networks, stratified by coastal and interior region (see *Parameters_BiomassAllometrySL.xlsx*). The coastal region was defined by the Coastal Western Hemlock and Coastal Douglas-fir BGC zones. Net growth of coarse and fine roots were estimated based on relationships between aboveground biomass and root biomass (Li et al., 2003) (see *Parameters_BiomassAllometryRoots.xslx*).

The efflux of carbon from biomass due to regular mortality (M_{Regular}) was calculated from a constant rate of regular biomass turnover ($\tau_{M,\text{Regular}}$) consistent with Kruz et al. (2009) (see *Parameters_BiomassTurnover.xslx*). Regular gross growth was calculated from:

$$G_{\text{Regular}} = \Delta B + M_{\text{Regular}} \quad \text{(Eq. 3)}$$

Note that Eq 3 is implemented prior to the introduction of catastrophic mortality, such that ΔB expressed regular rates of net growth. Biomass turnover due to litterfall (i.e., shedding of foliage, branches, bark, coarse roots, and fine roots) was constant (Kurz et al., 2009) (see *Parameters_BiomassTurnover.xslx*). Net primary productivity was calculated from the sum of annual gross growth and biomass loss due to litterfall (Clark et al., 2001; Gower et al., 1999, 2001; Grier and Logan, 1977):

$$NPP = G_{\text{Regular}} + LF \quad \text{(Eq. 4)}$$

Total stemwood volume was estimated from stemwood biomass assuming a constant carbon content of wood (Lamlom and Savidge, 2003) and species-specific estimates of wood density (*Parameters_WoodDensity.xlsx*) (Gonzalez, 1990). Merchantable volume was disaggregated from total volume using the ratio of merchantable and non-merchantable volume from TIPSY using the 12.5 cm utilization level.

5.4.2 Dead Wood, Litter and Soil Dynamics

The *DeadWoodLitterSoilDynamics* function estimated end-of-year carbon density (tC·ha^{-1}) of dead organic matter pools. This was achieved by estimating annual transfers of carbon from biomass to dead organic matter (i.e., tree mortality and turnover of non-stemwood biomass pools), consumption of dead organic matter by

[18] https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/forest-inventory/growth-and-yield-modelling

heterotrophs, atmospheric fluxes due to heterotrophic respiration, and redistribution of carbon associated with structural breakdown due to decomposition. Heterotrophic consumption was based on pool-specific Q_{10} functions of long-term mean air temperature (Kurz et al., 2009). The proportion of consumption emitted to the atmosphere vs. physical transfer between dead organic matter pools were based on pool-specific constants (Kurz et al., 2009). All parameters were stored in *Parameters_Decomposition.xlsx*.

5.4.3 Event Dynamics

The *EventDynamics* function estimated the effect of management and disturbance events on forest ecosystem carbon pools. The primary inputs to the function included indicators of event occurrence during the timestep, which were drawn from the historical observations (prepared in *dmec.pkl*), or from on-the-fly event simulation. The strategy was to use observed events where available, and default to simulators during periods when observations were unavailable (i.e., the pre-observation period and the future period) of the project. Event simulation for the pre-observation period played an important role in spinning up the carbon pools. Here, modelling projects were configured (see spin-up section of *ProjectConfig.xlsx*) so that wildfire events occurred at fixed return intervals over time that varied by BGC zone (see *Parameters_ByBGCZ.xlsx*). A spin-up period of 2000 years was adopted. Over future time periods, on-the-fly event simulations were drawn from event simulator (see Section 5.6.4).

The initial estimates of regular tree growth and mortality were updated to reflect any response to events. Depending on the type and severity of the disturbance, carbon was transferred from tree biomass to dead wood, dead organic matter, mills (i.e., removals), and piles, from dead wood to mills and piles, and from forest ecosystem to atmosphere through combustion. Composition of burning emissions followed those of Kurz et al. (2009). Parameters for transfers after an event are in *Parameters_Events.xlsx*.

Table 9. Sensitivity to events. For a complete summary of carbon pool source and sink responses specific to each event type see *Parameters_Events.xlsx*. For harvesting, see *Parameters_FelledFate.xlsx*.

Event type	Description of sensitivity
Aerial nutrient application	Aerial nutrient application events triggered a counter that stimulated temporary changes in net growth, biomass turnover due to litterfall and mortality, and heterotrophic respiration for a specified response duration (see *Parameters_NutrientApplications.xlsx*). Following aerial nutrient application, stand age was not updated. Fossil fuel emissions, emissions of CO_2 from hydrolysis of urea, and emissions of N_2O due to nitrification and denitrification were triggered in the year of application. Operational costs were also triggered in the year of application.
Artificial Stand Establishment	Artificial stand establishment triggered a change in growth curve from GC-A to a growth curve characterized by planting, GC-X + 1, where X was the ID of the preceding growth curve.

	Fossil fuel emissions were triggered in the year of the event. Operational costs were also triggered in the year of the event. Modelling did not explicitly include emissions from a silviculture survey in the year of planting. Instead, a set of fossil fuel emissions and costs were triggered in years offset from the year of the planting event. This included surveys that occurred in fixed years prior to, and following the planting event. Following planting, stand age was reset to zero.
Bark beetles	The relative effect of bark beetle occurrence on tree biomass due to tree mortality was defined by: $$M_{\text{Bark Beetle}} = M_{\text{Severity Class}} \times f_{\text{Host}} \times I_{\text{Age}} \qquad \text{(Eq. 5)}$$ where $M_{\text{Severity Class}}$ was the severity class-specific rate of mortality (see Insect Compilation dataset) and f_{Host} was the fraction of the stand comprised of vulnerable species (see *DisturbanceSpeciesAffected.xlsx*) and I_{Age} was a binary indicator preventing mortality from affecting stands with age < 20 years. Following bark beetle occurrence, stand age was not updated.
Clearcut Harvest	Clearcut harvest events were assumed to kill 100% of the live and standing dead trees. Felled organic material was removed, piled, or left distributed on site following region-specific assumptions (see *Parameters_FelledFate.xlsx*). Removed carbon (i.e., lateral wood transfers) followed region-specific assumptions about the mix of mills and exports (see *Parameters_RemovedFate.xlsx*). Following clearcut harvest, stand age was reset to zero. Assuming users rely on historical observations, the DMEC will include planting or direct seeding where it was reported by foresters. If foresters elected natural regeneration, the future growth curve remains on the pre-harvest growth curve (GC-A). Future (simulated) harvest events are always accompanied by a planting event with BGC zone specific planting assumptions (see gap-filling methods). Fossil fuel emissions were triggered in the year of the event. Operational costs were also triggered in the year of the event.
Defoliation by Hemlock Looper	In the absence of *Btk* treatment, a defoliation (insect code = “IDL”) event caused 100% tree mortality.
Defoliation by Western Spruce Budworm	In the absence of *Btk* treatment, a defoliation event (insect code = “IDW”) caused tree mortality following provincial forest health mortality assumptions (Maclauchlan et al., 2025) (see *DisturbanceSpeciesAffected.xlsx*).

Defoliator mitigation targeting Hemlock Looper	Treatments avoid 100% of tree mortality imposed by inciting event (Defoliation by Hemlock Looper)
Defoliator mitigation targeting Western Spruce Budworm	Methods under development.
Deforestation	A Deforestation event was always accompanied by a Regen Failure event, which set net growth of the active growth curve to zero.
Knockdown	Following knockdown, stand age was reset to zero. Fossil fuel emissions were triggered in the year of the event. Operational costs were also triggered in the year of the event.
Pile Burn	Pile Burn events led to 90% combustion of carbon in pile pools. The 10% carbon remained in remnant piles decayed at rates consistent with the medium litter pool. Fossil fuel emissions were triggered in the year of the event. Operational costs were also triggered in the year of the event.
Regen Failure	The Regen Failure event changes net growth of GC-A to zero.
Wildfire	The relative effect of Wildfire events on tree biomass due to tree mortality (M_{Wildfire}) was specific to burn severity rating (see *Parameters_BurnSev.xlsx*). Observations of burn severity rating became available in 2015. In the pre-observation and future periods, burn severity rating was predicted based on probability of burn severity rating fitted against the observations using multinomial logistic regression fits over 2015-2024 (see *Parameters_BurnSev.xlsx*). The fate of affected carbon pools was defined by pool transfer rules listed in *Parameters_Events.xlsx*. Following wildfire occurrence, stand age was updated as: $Age(t) = Age(t-1) \times (1 - M_{\mathrm{Wildfire}})$ (Eq. 6) Wildfires with 100% mortality triggered a transition from the active growth curve back to GC-1. Exceptions included straight-to-planting projects, where the preceding ('inciting') wildfire transitioned to a high burn severity growth curve.

5.4.4 Product Dynamics

The *ProductDynamics* function tracked stocks and annual emissions from wood products based on annual inputs of felled merchantable and non-merchantable carbon ($tC \cdot ha^{-1}$) following Dymond et al. (2016). A component of the inputs was converted into 'raw log' exports. A second component was converted to firewood and burned for the domestic electricity grid (both count as $BB_{Products}$). The remaining component was distributed among transient carbon pools representing pulp mills, lumber mills, plywood mills, OSB mills, and MDF mills. From the transient mill pools, the carbon was re-distributed among mills, or converted to in-use products. Disposal of in-use products was represented by transfers of carbon from in-use products to waste systems, including dumps and landfills, followed by gradual emissions from waste systems (see *Parameters_ProductDisposal.xlsx*). The carbon stored in in-use products and waste systems were not tracked spatially; the pools remained associated with the forest stand from which the felled carbon originated (see *Parameters_ProductTypes.xlsx*). Prior to 2024, the 100-year residence time of solid in-use products was ~33%. Starting in 2024, product disposal rate parameters were tuned so that the 100-year residence time of solid in-use products was 6% to align with provincial standards (OCF, 2024).

5.4.5 Geological Dynamics

The *GeologicalDynamics* function estimated emissions from fossil fuel consumption and could include substitution effects (for current projects substitution is excluded due to scientific confidence as described in 7.2.2). Methods adopted emission intensities associated with use of materials (aluminum, concrete, plastics, steel, and glass), and fossil fuels (coal, natural gas, oil) (see *Parameters_Biophysical.xlsx* with background information in *Workbook_Emission_Intensity.xlsx*). Total fossil fuel consumption was tallied from the sum of fossil fuel consumption associated with various operations (Table 10).

Table 10. List of processes with fossil fuel consumption.

Process	Description
Resource extraction and transport of logs to mills	Emission intensities ($tCO_2e \cdot m^{-3}$ harvested) were parameterized for milestones, including road construction, cruising and reconnaissance, felling, skidding, piling and sorting logs, loading logs at the landing, chipping, log transport from forest ecosystem to mill.
Mill operations	Emission intensities ($tCO_2e \cdot m^{-3}$ harvested) were parameterized for milestones, including unloading, sawing and processing lumber, plywood, OSB, MDF, pulp, pellets, size reduction, drying, pelletizing, and sieving.
Transport from mill to distribution hub	Emission intensity ($tCO_2e \cdot m^{-3}$ harvested) was parameterized for transport of lumber, plywood, OSB, MDF, paper and pellets from mills to Vancouver.

Transport from distribution hub to market	Emission intensities ($tCO_2e \cdot m^{-3}$ harvested) were parameterized for transport of solid wood products, raw log exports, and pellet exports.
Stand establishment	Emission intensities were parameterized for sowing and nursery operations (tCO_2e per seedling generated), planting (tCO_2e per ha planted), and silviculture surveying leading up to and following the planting milestone (tCO_2e per ha surveyed). Composted seedlings were a constant multiplier of seedlings planted. Area surveyed was a constant multiplier of area planted.
Aerial nutrient application	Emission intensities ($tCO_2e \cdot ha^{-1}$) were parameterized for milestones, including manufacturing of ammonia and urea (including *UCS*, Eq. 1), and transportation of the materials from the manufacturer to the sites of application. See *Workbook_Nutrient_Application.xlsx* for additional details regarding assumptions about the location of manufacturers and transportation distances.

This function also estimated substitution effects. Substitution effects consisted of use of bioenergy displacing coal, diesel, gas and oil at domestic and international forestry product-producing facilities, domestic independent power producers with electricity purchase agreements, bioenergy from pellet exports, bioenergy from domestic pellet use, and firewood consumption. Substitution effects also included displacement of concrete, steel, aluminum, glass, textiles, and plastics by use of sawnwood and panels. For each material, the substitution effect was estimated from the mass ratio of the displacing and displaced materials. This theoretical maximum effect was then reduced by a factor to reflect the potential alternative outcome of economic contraction.

5.5 Post-processing

Post-processing module, *cbrun_postprocess.py*, generated model output statistics (MOS), including indicators of central tendency and spread of the ensembles. Best estimates were based on the ensemble mean. All variables were stored to the MOS database. For example, mean stand age for a specified stratum (e.g., BGC zone = "CWH") and a specified scenario (e.g., scenario 1) is a "MOS variable". The post-processing design assumed that scenario comparisons were central to project analysis. Users defined all the scenario comparisons according to a scenario comparison name, and indices to the baseline and action scenarios that comprised the comparison. With this input, the post-processing functions generated the differences between 'action' and 'baseline' scenarios for each MOS variable. This included the difference in GHG emissions (ΔE). In large projects, the user specified up to four dimensions to stratify the MOS. In practice, the strata were used to query summary statistics for combinations of:

- Project type (e.g., "Underplanting")
- Year of implementation (e.g., "2024")

- Biogeoclimatic zone (e.g., “SBS”)
- Funding source (e.g., “FIP”).

A second post-processing function, *Calc_MOS_Map*, allowed users to query continuous spatial coverages for a specified set of MOS variables and a specified time horizon.

5.6 Supporting Modules

Depending on the project in question, modelling also relied on additional supporting modules.

5.6.1 BC 1 Hectare (*bc1ha*)

The *bc1ha* repository housed modules for processing geospatial data (*bc1ha_util.py*) and a command script (*bc1ha_com.py*) for executing the annual update process (see Section 4).

5.6.2 General Utilities (*macgyver*)

The *macgyver* repository housed modules for general utilities (*util_general.py*), geospatial processing (*util_gis.py*), generating graphics from model output (*util_fcs_graphs.py*), and utilities specific to modelling projects (e.g., *util_nm.py* and *util_nose.py*).

5.6.3 Forest Management Utilities (*hardhat*)

The *hardhat* repository housed modules for modelling forest management.

5.6.3.1 Economics

The *economics.py* module calculated annual costs, gross revenues, and net revenues based on the event types recognized by Forest Carbon Gadgets and the products recognized by Dymond (2012) plus pellets. From the project configuration spreadsheet, the module could be turned on or off depending on whether the user sought to calculate mitigation value (i.e., ‘cost-per-tonne’). Parameters were stored in *Parameters_CostsAndPrices.xlsx*.

5.6.3.2 Nutrient Applications

The *nutrient_application.py* module estimated effects of nutrient applications on forest ecosystem carbon and GHG emissions. When a nutrient application event occurred, it triggered a temporary increase in gross growth, mortality and litterfall and a temporary decrease in density of new wood growth and heterotrophic respiration of dead organic matter. Emissions of carbon dioxide following hydrolysis of urea (*VOL* in Eq. 1) occurred in the year of application. Emissions of nitrous oxide (*DEN* in Eq. 1) due to nitrification and denitrification of ammonia were assumed to occur in the year of application. The module also triggers additional consumption of fossil fuels in the year of application to account for production and transportation of fertilizer. Finally, it tracks sequestration of carbon dioxide in Industrial Product and Product Use (IPPU) sector (*UCS* in Eq. 1). *UCS* is equal to -1 × *VOL*. At present, no ‘piece-size effect’ was considered.

5.6.4 Event Occurrence Simulator (*taz*)

Without representation of future natural disturbances and management events (e.g., harvest), predictions of regular net growth may overestimate forest productivity. It is, therefore, important to consider future disturbance events. Modules to simulate event occurrence were stored in the repository, *taz*. These events were simulated on-the-fly by calling *taz* functions from the *EventDynamics* function that was executed within the annual process loop. From *ProjectConfig.xlsx*, each type of event simulation can be turned 'On' or 'Off' for each time period, including the pre-observation period, the observation period, and the future period. In practice, *taz* was responsible for simulating disturbance events during the pre-observation and future periods.

5.6.4.1 Default Statistical Event Occurrence Simulators

The *default_stat_event_sim.py* module housed functions to simulate the occurrence of discrete events on the fly (Table 11). The functions acted as default methods in the absence of more sophisticated simulators and will be replaced as more advanced methods become available. The degree of spatial variability captured by the simulators was specific to event type.

Table 11. List of event occurrence simulators.

Event type	Description
Wildfire	The *PredictWildfire_OnTheFly* function simulated future annual probability of wildfire occurrence. Annual probability of wildfire occurrence was calibrated against observations for each BGC zone using the historical wildfire perimeters dataset. To account for climate change, values increased linearly by 100% between 2025 and 2100. When a wildfire occurred, burn severity rating was predicted by drawing randomly from the observed frequencies of burn severity rating (see *Parameters_BurnSev.xlsx*).
Bark beetles	The *PredictMPB_OnTheFly* function simulated future annual probability of bark beetle occurrence and severity.
Clearcut harvest	The *PredictHarvest_OnTheFly* function simulated future annual probability of harvest occurrence. Probability was defined by three factors: 1) A map of annual probability of harvest fitted to historical harvest occurrence using logistic regression; 2) status of resource extraction restrictions (i.e., timber harvesting land base); 3) a sigmoidal function of current standing merchantable volume. The primary tuning parameter was the saturation level of the sigmoidal function. Unless otherwise specified, it was set to 4 % yr^{-1} across all BGC zones, which yielded a mean annual provincial harvest of 37 $Mm^3 \cdot yr^{-1}$ over 2025-2035. Consistent with observed harvest, simulated harvest events were implemented during the first day of the year. Clearcut harvest events were followed by the introduction of a pile burn event on day 2 of the year with probabilities of 0.33 and 0.66 in the coastal and interior regions, respectively.

Land use change	Future land use change events were not considered in the analysis. Exclusion of these processes was rationalized by lack of materiality in estimation and the exclusion status will be periodically reviewed and updated as needed.

5.7 Uncertainty

For both the FNM and NOSE modelling projects, the number of ensembles was set to N_{Ensemble} = 100. Best estimates of each variable were based on the mean of ensemble simulations. Various graphics were used to illustrate the degree of variability in potential outcomes resulting from stochasticity in the nature of disturbances.

5.8 Quality Assurance Measures

In advance of each annual update, a series of quality assurance (QA) steps were taken. Benchmarking exercises have become an important tool to evaluate model performance. In 2025, an intensive study was conducted to benchmark forest ecosystem carbon dynamics from Forest Carbon Gadgets against those of the Carbon Budget Model of the Canadian Forest Sector version 3, focusing on common silviculture investments in BC's forest sector (Hember and Satir, in prep).

Complex modelling projects were grounded through comparison with single-stand demonstration projects for common project types. These idealized, single-stand "demos" served a wide variety of purposes, including benchmarking results against those from more complex spatially-explicit modelling projects as a means of detecting obvious anomalies in model behaviour that may arise from changes in raw data sources, changes in the compiled modelling dataset, changes to model code, or changes to pre- and post-processing functions.

Table 12. List of quality assurance (QA) steps.

Step	Purpose
Run Clearcut Harvest demo project	• Confirm that the model maintained conservation of mass (i.e., confirm that change in total ecosystem forest carbon over time equals net carbon balance). • Confirm that Products module aligned with the Products Benchmark (6% residence time of in-use products after 100 years).
Run Underplanting demo project	• Record cumulative 2050 Δ*E* in the version tracking database.
Run Forest Nutrient Management demo project	• Record cumulative 2050 Δ*E* in the version tracking database.
Run Salvage Harvest and Planting demo project	• Record cumulative 2050 Δ*E* in the version tracking database.

Run province-wide project	• Confirm that future harvest simulations lead to a mean annual harvest yield of 30 $Mm^3\ yr^{-1}$ over the next ten years based on annual harvest volume projections[19].

5.9 Project Setup and Workflow

This section describes the steps taken to prepare a modelling project. This section refers to modules by their handles (see Table 1).

5.9.1 File Organization

Modelling projects adopted a filing system that connected the code, general data sources, and project data (Table 13). Pre-processing functions, the model functions, and post-processing functions were executed from a single project script that was accessed by an integrated development environment (e.g., Spyder[20]).

Table 13. Guidance on how to organize code and data for modelling.

Type	Description
Code:	
Model functions	A folder containing the model *(e.g. C:\Code_Python\fcgadgets\)*
Project scripts	A folder containing command scripts for individual modelling projects *(e.g. C:\Code_Python\bc-fcs\bcfcs_fnm.py)*
Primary & Secondary Data:	
Geodatabases	A folder containing the source geodatabases *(e.g. C:\Data\Geodatabases\)*
Raster database	A folder containing the bc1ha raster database *(e.g. C:\Data\BC1ha\)*
Parameters database	A folder containing all model parameters *(e.g. C:\Code_Python\fcgadgets\Parameters\)*
Project-specific Data:	A location to store project-specific data
Project input data	*(e.g. C:\Data\Modelling Projects\BCFCS\BCFCS_FNM\Inputs\).* This includes: • Metadata (*meta.pkl*), • Land surface attributes (*lsat.pkl*) • Disturbance and management event chronology (*dmec.pkl*) • Growth curves (*gc.pkl*).

[19] https://www.bcbudget.gov.bc.ca/2025/pdf/2025_budget_and_fiscal_plan.pdf

[20] www.spyder-ide.org/

	(e.g. C:\Data\Modelling Projects\BCFCS\BCFCS_FNM\Outputs\)

5.9.2 Pre-processing Steps

All projects follow the same pre-processing steps:

1. Manually create Project Data folder and copy input data files.
2. Manually define project- and scenario-specific parameters in a spreadsheet *ProjectConfig.xlsx* (located in the Inputs folder of the Project Data folder) and save.
3. Manually create a project script (copy a pre-existing project script). The following steps are demarcated by cells (separated by #%% tags) within the project script.
4. Import required modules.
5. Initialize the project by running *u1ha.Init*. This creates a data structure called *meta* that tracks all the information about the project. The *Init* function imports:
   a. Geospatial reference system.
   b. Model parameters.
   c. Project- and scenario-specific parameters (from the *ProjectConfig.xlsx* spreadsheet).
6. Manually define project name (e.g., "BCFCS_FNM").
7. Manually define the path to Project Data (e.g., *C:\Data\Modelling Projects\BCFCS\BCFCS_FNM*).
8. Manually define the path to folder containing output graphics for the project (optional).
9. Import the Project Configuration Spreadsheet (prepared by user in step 2) using *cbu.ImportProjectConfig.*
10. Manually define indices to the baseline scenarios and indices to the action scenarios.
11. Import the LSAT and DMEC using *prep.Process1_ImportVariables.*
12. Prepare the input parameters for *BatchTIPSY.exe* using *prep.Process2_PrepareGrowthCurves.*
13. Open and run *GrowthCurvesTIPSY_Output.BTP* to generate growth curves using *BatchTIPSY.exe*.
14. For large projects, define how the model output statistics will be stratified using *DefineStrata* (optional).
15. Generate input files for LSAT, DMEC and GC using *prep.Process3_PrepInputsByBatch*.

5.9.3 Simulation

To run the model, execute *cbr.MeepMeep*.

5.9.4 Post-processing Steps

This section describes the steps taken to analyze output from the model run. The post-processing steps consisted of:

1. Compute model output statistics for core variables using *post.Calc_MOS_GHG*.
2. Compute model output statistics for economic variables using *post.Calc_MOS_Econ* (optional)
3. Compute model output statistics for event areas using *post.Calc_MOS_Area*.

4. Compute model output statistics for mortality by driving agent using *post.Calc_MOS_MortByAgent* (optional).
5. Import model output statistics using *post.Import_MOS_ByScnAndStrata_GHGEcon*.
6. If the user seeks to compare scenarios, manually list the Scenario Comparisons to be analyzed. For each Scenario Comparison, the user must define a name (e.g. "FNM with Harvest") and the indices to the baseline and action scenarios being compared (optional).
7. Compute the (action – baseline) differences for each variable using *post.Import_MOS_ByScnComparisonAndStrata* (optional).
8. Analyze model output statistics using a variety of pre-built functions developed to support quality assurance and summary of results in tabular and graphical format.

6 Attribution

6.1 Background

In most economic sectors, GHG emissions are driven solely by human actions. In the land sector, net emissions are driven by a combination of natural and human-caused processes. This introduces additional complexity in the way climate change mitigation performance is measured in the forest sector. Signatories of the United Nations Framework Convention on Climate Change (UNFCCC) are encouraged to partition total emissions into components indicating emissions caused by 'natural' and 'anthropogenic' actions[21].

Isolating anthropogenic emissions is an exercise in attribution, defined in AR6-WG1 Box TS.1 as: *"Attribution is the process of evaluating the relative contributions of multiple causal factors to an observed change in climate variables (e.g., global surface temperature, global mean sea level), or to the occurrence of extreme weather or climate-related events. Attributed causal factors include human activities (such as increases in greenhouse gas concentration and aerosols, or land-use change) or natural external drivers (solar and volcanic influences), and in some cases internal variability"* (IPCC, 2022). For additional background information about detection and attribution in climate science, see AR5-WG1 Box 10.1 (Bindoff et al., 2014).

Two approaches have been developed to isolate the component of net emissions attributed to anthropogenic actions. Starting in 2018, some NGHGIs expanded from just reporting net emissions to including estimates of anthropogenic emissions. The methods were shaped by a stated priority to remain compliant with earlier IPCC Good Practices Guidance (Penman, 2003), culminating in a set of rules that partition land area into anthropogenic or natural categories depending on time since natural disturbance (Kurz et al., 2018). Emissions attributed to humans were then defined by net emissions from the land area categorized as anthropogenic.

[21] Direct anthropogenic emissions are defined by those directly attributed to human actions (i.e., forest management and land use change). Values exclude indirect anthropogenic emissions (i.e., human-caused changes in atmospheric CO_2 concentration, nitrogen deposition, acid deposition, and human-caused climate change).

Alternatively, the global carbon budget project (GCBP)[22] relies on scenario comparisons to attribute variation in net emissions to specific forcings (Friedlingstein et al., 2022; Piao et al., 2009; Prentice et al., 2001). The baseline and action scenarios, respectively, mimic the control and treatment samples in a formal experiment. Estimates of anthropogenic emissions differ between the area-partitioning approach adopted by NGHGIs and the scenario comparison approach adopted by GCBP (Friedlingstein et al., 2022; Grassi et al., 2023; IPCC, 2022).

6.2 Attribution from Scenario Comparisons

This methodology adopted the scenario comparison approach because: 1) it follows norms of attribution in climate science (Bindoff et al., 2014; IPCC, 2022); 2) it is more conducive to attribution at a more granular level (i.e., at the scale of action categories); 3) it aligns with other investment-scale reporting initiatives[23] and; 4) it is not obligated to follow internationally-negotiated methods of NGHGIs. Total anthropogenic emissions attributed to silviculture investments, herein called "GHG impact," was estimated from a tally of those from specific action categories:

$$\Delta E_{\text{Silviculture Investments}} = \Delta E_{\text{NOSE}} + \Delta E_{\text{FNM}} + \Delta E_{\text{DM}} \quad \text{(Eq. 8)}$$

where NOSE is non-obligation stand establishment, FNM is forest nutrient management, and DM is defoliator mitigation. Distinct modelling projects were established at the level of each action category. For each action category, anthropogenic emissions were defined by the difference between emissions for an action scenario (with investments in the focal action) and a counterfactual baseline scenario (without investments in the focal action). For example, the GHG impact from non-obligation stand establishment were estimated as:

$$\Delta E_{\text{NOSE}} = E_{\text{Action}} - E_{\text{Baseline}} \quad \text{(Eq. 9)}$$

where E_{Action} and E_{Baseline} were both calculated from Eq. 1 for a spatial footprint of operations specific to each action category. Values, ΔE, indicate the GHG impact attributed to the focal event(s), including sowing the seeds, surveying the land, planting the trees and any other actions linked to the investment decision. A positive value of ΔE at a specific time, or over a specific time interval, indicated that the actions increased the concentration of atmospheric GHGs, while a negative value of ΔE indicated that the actions decreased the atmospheric concentration of GHGs.

The baseline scenario excluded the focal milestone and any other milestones associated with, or incentivized by, the investment. For example, in Innovative Timber Sale Licenses[24], it was assumed that investments in tree planting, in part, incentivized the preceding salvage harvest milestone. The emission impact from the salvage harvest milestone was, therefore, counted in the estimation. The focal milestone was commonly associated

[22] https://globalcarbonbudget.org/

[23] https://ww2.arb.ca.gov/our-work/programs/california-climate-investments

[24] https://www2.gov.bc.ca/gov/content/environment/natural-resource-stewardship/land-based-investment/forests-for-tomorrow/stand-establishment-and-treatment-standards/over-storey-removal-for-innovative-timber-sale-license-itsl

with milestones that had no material impact on forest ecosystem emissions, but still introduced upstream emissions and material costs or revenues.

There is room for confusion arising from differences in the definition of baseline scenarios between BC-FCS and BC's Forest Carbon Offset Protocol 2.0 (FCOP2)[25]. In FCOP2, the word "baseline" describes the projected implementation of a portfolio of actions at an assumed annual implementation level that portrays the continuation of historical policies and practices. As such, 'incrementality' (or 'additionality') is inherently considered in the calculation of emissions when using FCOP2. In the BC-FCS, the word "baseline" is reserved to the estimation of emissions had the focal actions not occurred. As such, the estimate of ΔE from BC-FCS describes the total GHG impact from all operations and makes no distinction between incremental and non-incremental emissions (see Section 7 for additional details).

6.3 Complexities Arising from Categorization of Emissions

Multiple action categories may spatially overlap. Where overlap may occur, the investments may impose interactive effects on GHG impact. Here, action categories were calculated across the complete footprint of operations for each action category, irrespective of any spatial overlap with other action categories. As non-focal actions were represented in the baseline and action scenarios, there should be no substantial double-counting when results from each action category are summed.

Within an action category, investments from the current year may spatially overlap with investments in previous years. This means that the historical footprint of operations may have an area that is less than the sum of all historical treatment areas (e.g., repeat nutrient applications, or re-planting on previously planted areas).

All reporting of investments was anchored to the calendar year that the most recent focal milestone was recorded as complete. The GHG impact can deviate from zero prior to the focal milestone. For example, if the focal milestone is planting, and it was preceded by overstory removal three years prior to the planting, ΔE will deviate from zero prior to the year of reporting. This decision partially reflected limitations in the ability to detect non-obligation stand establishment prior to completion of the planting milestone.

The footprint of action categories may comprise specific project types (e.g., stand establishment types, Table 4). At any given location, the GHG impact from each project type was anchored to time according to the last instance of the focal milestone. For a specific annual release, one can sum the GHG impact from all project types without double-counting. To get an accurate historical account of Salvage and Planting or Underplanting, one must aggregate those project types with Replanting and Fill Planting, where the latter events have subsequently occurred.

[25] https://www2.gov.bc.ca/gov/content/environment/climate-change/industry/offset-projects/offset-protocols

7 Accounting

This section describes the methodology used to determine which GHG emissions were included or excluded from measures of climate change mitigation performance.

7.1 Accountable Emissions

The above sections describing estimation and attribution established estimates of total anthropogenic emissions from all “recognized” processes. Accounting makes a distinction between “recognized” and “accountable” emissions. The BC Ministry of Forests uses the tally of accountable emissions as a formal measure of climate change mitigation performance. Recognized emissions might be excluded from the tally of accountable emissions for the following reasons:

1. To avoid conflict with policies aiming to protect public health and safety.
2. To incentivize climate action.
3. To maintain a degree of scientific confidence.
4. To focus resources on processes with materiality.
5. To avoid double-counting.

Accountable emissions were characterized by those that met a list of accounting inclusion criteria (AICs) (Section 7.2). Failure to meet any individual criterion led to exclusion from the tally of accountable emissions. Failures to meet AICs (“exclusions” herein) could, in principle, be decided at the scale of specific biophysical processes, funding sources, or action categories. On an annual basis, the methodology consisted of reviewing and updating the accounting inclusion status of biophysical processes, funding sources, and action categories to reflect potential changes in data collection, science, accounting policy (i.e., how the exclusions are defined), and contributing funding sources. There is an expectation that the current exclusion status of some processes will eventually be revised in accordance with continuous improvement plans.

7.2 Accounting Inclusion Criteria

7.2.1 Controllability

To be included in a tally of accountable emissions, emissions needed to be “controllable”. This step incentivized climate action by avoiding judging actors based on factors that were beyond their control. This prevented actors from taking credit for removals (i.e., negative emissions) that occurred naturally, and it avoided debiting actors for emissions that occurred naturally. In so doing, actors were not dissuaded from taking action despite operating in a system that was an overall source of carbon. Isolating the anthropogenic component of total emissions (see Section 6) was the main strategy used to define controllable emissions. At this time, no additional conditions were applied that would further differentiate controllable emissions from anthropogenic emissions.

Although emissions resulting from natural disturbances (e.g., wildfire) are largely uncontrollable, the adoption of Eq. 9 means that a proportion of wildfire emissions were attributed to human actions and, therefore, counted in the tally of anthropogenic emissions. For example, if stand establishment was successful in the objective to increase carbon stocks across forest landscapes, it increased the amount of carbon that was susceptible to combustion when future wildfires occurred. The probabilities of wildfire occurrence and severity remained the same between the baseline and action scenarios, but there was more carbon available to burn in the action scenario. We describe this as first-order negative feedback responses to forest management. Second-order feedback responses were defined by the additional consideration of potential effects of the focal actions on the probability of disturbance occurrence and/or severity, which will mediate the above first-order effects. These second-order effects were not considered in the modelling. That is, implementation of the action categories were assumed to impose no effects on future probability of disturbance occurrence or severity.

7.2.2 Scientific Confidence

To be included in a tally of accountable emissions, fluxes needed to be estimated to an acceptable standard of scientific confidence. Fully conveying that standard and defending every decision was beyond the scope of this methodology. Instead, priority was placed on disclosing the decisions. To promote transparency, supplementary materials may report estimates that include “recognized” emissions for comparison with tallies of accountable emissions.

7.2.3 Incrementality

The focus of this initiative was to report the impact of all operations from each action category. Incrementality (also known as additionality) was not considered among accounting inclusion criteria. That is, accountable emissions did not exclude a component of implementation deemed to be non-incremental. As such, 100% of the implementation level of each action category was deemed to count toward GHG impact. Any increase in accountable ΔE was perceived to be a contribution to anthropogenic climate change. Any decrease in accountable ΔE was perceived to be a contribution to mitigation of anthropogenic climate change. Any additional steps to describe performance relative to a historical reference year (or reference period) were left to the discretion of users.

7.2.4 Mandate

This reporting initiative was focused on reporting climate action from investments and programs administered by the BC Ministry of Forests. Various actions were beyond the scope of this reporting initiative because they were not administered by BC Ministry of Forests, or because BC Ministry of Forests and partner agencies reported specific actions elsewhere. This criterion helps to avoid double-counting of emissions.

7.2.5 Materiality

Some processes deemed to have a negligible contribution may be excluded from the tally of accountable emissions.

7.3 Accounting Inclusion Status

Current exclusion decisions are listed in Table 14.

Table 14. List of recognized processes that are currently excluded from tally of accountable emissions.

Exclusions	Type of Exclusion	Rational
Lateral river transport (LR_{Total})	Biophysical process	Excluded from accountable emissions due to high uncertainty and lack of evidence.
Substitution effects ($FF_{Substitutions}$ and $CP_{Substitutions}$)	Biophysical process	Excluded from accountable emissions due to high uncertainty. Preliminary estimates shown in tally of recognized emissions.
International component of forest ecosystem fluxes ($RH_{International}$, $BB_{Wildfire, International}$, $BB_{Open\ Burning, International}$, $VOL_{International}$, $DEN_{International}$, $NPP_{International}$)	Biophysical process	Excluded from accountable emissions due to high uncertainty. In so doing, the model implicitly omitted any interactions between the domestic and international forest sector arising from the trade of wood products. This was analogous to setting a 'leakage factor' to zero (see BC's Forest Carbon Offset Policy for a description of leakage[26]).
Future land use change	Biophysical process	Excluded from accountable emissions due to lack of materiality. Work is in progress to improve assumptions about future rates of land use change.
Green initiatives in seedling production	Biophysical process	Excluded from accountable emissions due to lack of materiality. Work is in progress to improve sensitivity to change in practices in operations leading up to stand establishment.
Biogeophysical radiative forcing	Biophysical process	Excluded from accountable emissions due to high uncertainty. The focus of this methodology was on estimating the impact of silviculture investments on the abundance of atmospheric GHGs, which expressed biogeochemical radiative forcing on the Earth's climate. Such actions can also affect climate by altering surface climate, for example, through change in surface albedo, convective heat fluxes, and moisture recycling (Bonan, 2008; Lawrence et al., 2022; Marland et al., 2003). Collectively referred to as biogeophysical radiative

[26] https://www2.gov.bc.ca/gov/content/environment/climate-change/industry/offset-projects/offset-protocols

		forcing, the modelling of these processes remains under investigation.
Sensitivity of future disturbance probability of occurrence and severity to forest management actions.	Biophysical process	Actions were assumed to impose no effect on future annual probability of occurrence and severity. Excluded due to lack of scientific confidence.
Defoliator mitigation targeting Western Spruce Budworm	Action category	Excluded from accountable emissions due to high uncertainty. Subject to periodic review of ongoing research into the efficacy of treatments targeting western spruce budworm, insect code = "IDW" (*Choristoneura occidentalis*).
Fibre utilization	Action category	Excluded from accountable emissions to avoid double-counting.
Licensee operations (road construction, harvesting, site preparation, and any voluntary climate action by licensees)	Action category	Excluded from accountable emissions to avoid double-counting.
Stand establishment achieved through Forest and Range Practices Act Section 108	Funding source	Excluded from accountable emissions due to high uncertainty in baseline scenario assumptions.
Stand establishment with "NSR backlog" ASET (see Table 4)	Funding source	Excluded from accountable emissions to avoid double-counting.
Stand establishment led by non-government agencies	Funding source	Excluded from accountable emissions to avoid double-counting.

8 Reporting

8.1 Annual Releases

The BC Ministry of Forests compiled field data from the most recent complete year by March 31 of the following year. Between March 31 and July 15, modelling projects were completed to update the summary database.

Upon release, each update replaced previous estimates as the official source. Estimates from previous releases became out of date, as some stands treated in previous years subsequently experienced post-treatment management and natural disturbance events. This periodically also led to reclassification of project type (e.g., a transition from Underplanting to Fill Planting) for a specific location. The previous Underplanting remained counted as area treated, and the emissions, costs and revenues associated with that event remained, but the emissions were counted in the Fill Planting project type instead of the Underplanting project type.

8.2 Implementation Period

To support various information requests, accountable emissions were summarized according to specific time periods over which implementation occurred.

Table 15. List of implementation periods. CAP: climate action plan.

Implementation Period	Description
Completed Operations	Operations listed as complete between 1971 and the most recent complete year
Current Operations	Operations listed as completed during the most recent complete year. See BC Ministry of Forests Service Plan Progress Report.
Future Operations	Operations projected by CAPs. See BC Ministry of Forests Service Plan Target.
Completed and Future Operations	A combination of operations listed as complete between 1971 and the most recent complete year and operations projected by CAPs

8.2.1 Completed Operations

The spatial domain for each modelling project was defined by a binary mask indicating the footprint of investments for each action category as recorded in BC's official forest sector information systems (see Sections 4 and 5). The conditions included:

- Focal milestone listed as complete in government information systems.

- Located on public BC land.
- Occurring between 1971 and the most recent completed year.

8.2.2 Future Operations

Future rates of implementation, $A_{\text{Projected}}$ ($\text{ha}\cdot\text{yr}^{-1}$), for FNM and NOSE were drawn from the Forest Investment Program Strategic Plan[27]. Estimation of emission impacts attributed to future years of projected operation, i = 1…m, was based on the efficacy and assumed future rates of implementation for of j = 1…n project types:

$$\Delta E_{\text{Projected Operations},i} = \sum_{j=1}^{n} Efficacy_j \times A_{\text{Projected},i,j} \quad \text{(Eq. 10)}$$

Efficacy was defined by the mean per-hectare cumulative Δ*E* by 2050 ($tCO_2e\cdot ha^{-1}$) estimated from the most recent completed year of operations for each project type. In essence, the method took the modelling results from analysis of the most recent complete year of operations and moved the results forward in time.

Table 16. Assumed relative allocation of action categories by project type.

Action category	Project type	Proportion of total implementation (%)
Forest nutrient management	Aerial nutrient application	100
	Hand application	0
	Organic application	0
Non-obligation stand establishment	Underplanting	80
	Salvage and Planting Post Beetle	20
	Salvage and Planting Post Other	0
	Knockdown and Planting	0
	Replanting	0
	Fill Planting	0
Defoliator Mitigation	Targeting Western Spruce Budworm[28]	0
	Targeting Hemlock Looper[29]	0

[27] https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/forest-investment-program#strategy

[28] Accounting inclusion status under review.

[29] Infestations tend to follow a ten-year cycle, deemed too difficult to forecast in advance, not recognized in projection.

8.3 BC Ministry of Forests Service Plan

The BC Mistry of Forests Performance Measure is a tally of accountable GHG impacts from NOSE, FNM and DM action categories[30]. Where possible, all reporting focused on estimates of cumulative GHG impact between a defined "current year" and 2050 to align with a CleanBC target reporting year[31]. Other target years, such as 2030, 2040, and 2100 were recorded in the Summary Database (Figure 1). The "Actual" performance measure was based on the Current Operations implementation period, while the "Target" performance measure was based on the Future Operations period of implementation (see Section 8.2).

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[30] https://www.bcbudget.gov.bc.ca/Annual_Reports/2023_2024/pdf/ministry/for.pdf

[31] https://www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-forecast

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