Forest Research

CARBINE-R User Guide

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Preface

This guidance document aims to help users access and run CARBINE-R. It does not go into technical detail about the CARBINE-R model. For such information, please see the CARBINE-R Technical Guide.

Quick Start Guide

For those familiar with R, the quick start guide below summarises the steps to set up and run CARBINE-R. For more detailed steps on R installation and setup of the R environment, see section 2.3. For steps on how to run CARBINE-R, and how to change run settings, see section 3.

1) Ensure R v4.4.2 and Rtools v4.4 (or newer) are installed.
2) Download and unzip the CARBINE-R folder.
3) Open the "carbine_r" R project file in RStudio.
4) For the first time opening the project, run the 'renv::restore()' command to load required packages for model running.
5) Edit the config file (CARBINE-R/0_carbine_config.xlsx) to desired settings (or you can run with default settings in the file). Save the file (under any name, but keep as .xlsx file type).
6) Open the "R\carbine_start.R" script and click the 'source' button.
7) When prompted, select the required config file.
8) The main outputs can be viewed in the R environment and as .csv files in the output folder (in a subfolder with the project name specified in the config file). These files are:
    - 'ghgi_output': carbon stocks summarised by afforestation year and reporting year. Saved as 'ghg_inventory_output.csv'

- ‘annual_carbon_stocks’: carbon stocks summarised by reporting year only. Saved as ‘annual_carbon_stocks.csv’
- ‘single_stand_annual_carbon_stocks’: an output for single stand runs only, which combines the carbon stocks summarised by reporting year with metadata on the stand species, management, etc. Saved as ‘single_stand_annual_carbon_stocks.csv’

9) Other data and plot outputs for single-stand runs can be set up in the config file (see section 3.3).

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1. Introduction to CARBINE-R

1.1. Brief model description

CARBINE is a forest carbon accounting model developed by Forest Research. CARBINE-R is the latest iteration of the model, re-written in the 'R' language to facilitate the model becoming openly accessible.

The CARBINE model works at a forest stand level, modelling carbon stocks on a per hectare (ha) basis. CARBINE is parameterised to model carbon stocks for 19 tree species at a range of growth rates and under a variety of configurable management settings. CARBINE can assess carbon stocks over long periods and multiple rotations of trees. The model produces outputs for the carbon stocks held in trees, litter, deadwood, soil and harvested wood product pools. The model has been developed over many years, taking into account UK specific data where possible, and aligning with IPCC guidance. The model is intended for large-scale analysis of forest carbon dynamics, such as at a national or regional scale.

CARBINE-R relies on two models which have been developed into R packages. These models are M1R and ScotiaR. M1R is a stand-level growth model which CARBINE-R uses to estimate tree growth and harvest regimes. ScotiaR is a litter, deadwood, and soil model. It estimates the transfer of carbon from litter and deadwood pools into the soil, estimating soil carbon stocks for a range of soil types.

A model diagram is presented in Figure 1 (section 1.5). For more detailed information on the scientific basis and model coding structure, see the CARBINE-R Technical Guide.

1.2. R project structure

The CARBINE-R model is built as an RStudio project, which organises all the folders, files and resources needed for an R analysis in a single folder. This means that all file paths are linked to this single folder, eliminating the need to manually

update file paths on different machines. The main folders and files within the project are described in Table 1.

Table 1. Folder structure of the CARBINE-R project. The main folders a user may interact with are indicated in the second column. Other rows show folders which should not require any interaction but should not be deleted from the project.

Main folders/ files	User interaction likely?	Contents
Input	Yes	Input datasets for model, including tree stand data and parameter datasets. Subfolders include: • management_prescription: folders containing different management prescriptions depending on the run type. • parameters: folder of input parameters. • weather: contains default weather files for each nation.
Output	Yes	Outputs of model runs, which are saved in named subfolders, where the name depends on either the test case number or the project name given in the config file.
R	Yes	Folders of R scripts for each module, in numbered running order.
carbine_r.Rproj	Yes	This file opens up the R project, with all configurations and filepaths set up.

Main folders/ files	User interaction likely?	Contents
0_carbine_config.xlsx	Yes	The 'config file'. This editable file contains the settings to define the type of CARBINE run and change the inputs and output options.
Renv	No	Folder containing files to manage the R environment, i.e., required packages etc.
Extdata	No	Files needed for running of M1R package.
.git	No	Files used for Git version control.

1.3. Inputs

1.3.1. Config file

The config file ('0_carbine_config.xlsx') should be edited by the user to set the CARBINE run settings, such as project name and run type. It is also where the weather file can be selected. Currently, a single CARBINE run can only use a single weather file. Therefore, if you want to run CARBINE to compare different weather inputs, you will need to create multiple config files, each selecting a different weather file. The config file is also where data and graph output options can be selected (see section 3.3), and where parameter inputs can be changed (see section 3.4). Multiple config files can be prepared and saved under different names and then selected as needed. Note that different project IDs will need to be given in each config file, otherwise outputs will overwrite each other in different runs.

For users not wishing to modify the CARBINE-R model itself, but only change inputs, the config file is the only file that needs to be edited. Full details on how to interact with the config file can be found in section 3.

1.3.2. Spplist

The spplist file details the stand_prescription to be modelled in CARBINE. Each stand prescription defined in this file consists of the tree species, yield class, management (thinning and clearfelling specifications), fallow length and 'LISS overlap period length' (see glossary for definitions). The spplist file can list either a single stand prescription (a single-stand run), or multiple stand prescriptions (a multi-stand run). The stand prescription can describe different management periods, where stands undergo transitions from one period of management to another. These transitions are identified by a calendar year value.

Default spplist files are supplied with the test cases and for Northern Ireland for a GHG inventory type run.

Bespoke spplist files can be generated using the spplist template file. See section 3.2.3 for details.

1.3.3. Area files

An area file is created for each of the stand prescriptions listed in the spplist file. These define the areas of the stand prescription created or 'afforested' (planted with trees for the first time) in each year.

Area files are linked to stand prescriptions in the spplist file by a shared 'area code', in the format of 'AREAXXXX', such as 'AREABCCC'.

Further description can be found in the technical guide.

1.3.4. Deforestation

Deforestation is included in CARBINE-R as annual percentages of stand areas which are deforested. For GHG inventory runs, deforestation rates are estimated from

preparatory calculations not covered in this guide. Illustrative deforestation rates are provided for some test case runs.

1.3.5. Parameters

CARBINE uses a wide array of parameters. The parameters usually used for GHG inventory calculations are selected by default, but alternative parameter files can be specified in the config file (see section 3.4 for more details).

1.4. Outputs

1.4.1. Main outputs

At the end of a full model run, CARBINE-R provides the following main outputs.

GHG inventory output

This is the output format used for the GHG inventory and has the file name 'ghg_inventory_output.csv'. For each output value, the carbon stocks are reported for each afforestation year and reporting year, consisting of:

- Carbon stocks for the whole forest including areas that are deforested in the reporting year (prior to deforestation occurring), 'before'
- Carbon stocks for the whole forest excluding areas that are deforested in the reporting year, 'after'
- Carbon stocks for the area deforested in the reporting year, before deforestation occurs, 'defor'.

The output type has a specific format for use in GHG inventory calculations. Some of the reasons behind the formatting are described below:

- Values are grouped by each afforestation year so that a 20-year transition period between forest remaining forest and land converted to forest can be calculated for each reporting year.

- Values for tree carbon 'before' and 'after' subtraction of any losses (e.g. mortality, harvesting) are calculated so that annual net change can be calculated
- The 'after' and 'defor' values for non-tree values (litter, deadwood and soil) are used to calculate the dead organic matter on deforested sites so this can be used to report these carbon stocks after land use change. The 'before' value is vestigial but it can be useful for debugging as it should equal the combined 'after' and 'defor' values.

Multi-stand results are aggregated by summing values across the same afforestation year and reporting year. Therefore, there may be multiple results for each reporting year, depending on the number of afforestation years. The format of this file is described in Table 2.

Table 2. Structure of the ghg_inventory_output file. Carbon values are presented in tonnes, and areas are in hectares. Where it is specified that values represent results at the 'end of the reporting year' this indicates that these values allow for transfers of carbon out of and into different carbon pools (e.g. trees, litter, soil) resulting from processes of turnover, mortality, harvesting and decay.

Column name	Description
afforestation_year	Calendar year in which the area is planted with trees for the first time
reporting_year	Calendar year for which carbon stocks are being reported for the given afforestation year
forested_area	Forest area for the given reporting and afforestation years (after deforestation)
deforested_area	Deforested area for the given reporting year and afforestation year

Column name	Description
carbon_before_tree_main_crop	Whole tree carbon for the reporting year / afforestation year combination before subtracting any losses on non-deforested land
carbon_after_tree_main_crop	Whole tree carbon for the reporting year / afforestation year combination after subtracting losses (i.e. turnover, harvest and mortality) on non-deforested land
carbon_above_ground_tree_before_thin	Above ground tree carbon for the reporting year / afforestation year combination before subtracting any losses on non-deforested land
carbon_above_ground_tree_main_crop	Above ground tree carbon (stem, branches, and foliage) for the reporting year / afforestation year combination after subtracting losses (i.e. turnover, harvest and mortality) on non-deforested land
carbon_below_ground_tree_before_thin	Below ground tree carbon (coarse roots and fine roots) for the reporting year / afforestation year combination before subtracting any losses on non-deforested land

Column name	Description
carbon_below_ground_tree_main_crop	Below ground tree carbon (coarse roots and fine roots) for the reporting year / afforestation year combination after subtracting losses (i.e. turnover, harvest and mortality) on non-deforested land
carbon_defor_tree_main_crop	Whole tree carbon for the reporting year / afforestation year combination after subtracting losses (i.e. turnover, harvest and mortality) on deforested land
carbon_before_litter	Carbon in the litter pool on both deforested and non-deforested land at the end of the reporting year (for a given afforestation year)
carbon_after_litter	Carbon in the litter pool on non-deforested land at the end of the reporting year (for a given afforestation year)
carbon_defor_litter	Carbon in the litter pool on deforested land at the end of the reporting year (for a given afforestation year)
carbon_before_deadwood	Carbon in the deadwood pool on both deforested and non-deforested land at the end of the reporting year (for a given afforestation year)

Column name	Description
carbon_after_deadwood	Carbon in the deadwood pool on non-deforested land at the end of the reporting year (for a given afforestation year)
carbon_defor_deadwood	Carbon in the deadwood pool on non-deforested land at the end of the reporting year (for a given afforestation year)
carbon_before_ara1	Carbon in soil on non-deforested and deforested land at the end of the reporting year (for a given afforestation year); assumption of sand soil type (1) and formerly arable land use.
carbon_after_ara1	Carbon in soil on non-deforested and deforested land after subtracting any losses at the end of the reporting year (for a given afforestation year); assumption of sand soil type (1) and formerly arable land use.
carbon_defor_ara1	Carbon in soil on deforested land after subtracting any losses at the end of the reporting year (for a given afforestation year); assumption of sand soil type (1) and formerly arable land use.

Column name	Description
carbon_before_ara2	Carbon in soil on non-deforested and deforested land at the end of the reporting year (for a given afforestation year); assumption of loam soil type (2) and formerly arable land use.
carbon_after_ara2	Carbon in soil on non-deforested and deforested land after subtracting any losses at the end of the reporting year (for a given afforestation year); assumption of loam soil type (2) and formerly arable land use.
carbon_defor_ara2	Carbon in soil on deforested land after subtracting any losses at the end of the reporting year (for a given afforestation year); assumption of loam soil type (2) and formerly arable land use.
carbon_before_ara3	Carbon in soil on non-deforested and deforested land at the end of the reporting year (for a given afforestation year); assumption of clay soil type (3) and formerly arable land use.

Column name	Description
carbon_after_ara3	Carbon in soil on non-deforested and deforested land after subtracting any losses at the end of the reporting year (for a given afforestation year); assumption of clay soil type (3) and formerly arable land use.
carbon_defor_ara3	Carbon in soil on deforested land after subtracting any losses at the end of the reporting year (for a given afforestation year); assumption of clay soil type (3) and formerly arable land use.
carbon_before_ara4	Carbon in soil on non-deforested and deforested land at the end of the reporting year (for a given afforestation year); assumption of organoclay soil type (4) and formerly arable land use.
carbon_after_ara4	Carbon in soil on non-deforested and deforested land after subtracting any losses at the end of the reporting year (for a given afforestation year); assumption of organoclay soil type (4) and formerly arable land use.

Column name	Description
carbon_defor_ara4	Carbon in soil on deforested land after subtracting any losses at the end of the reporting year (for a given afforestation year); assumption of organoclay soil type (4) and formerly arable land use.
carbon_before_ara5	Carbon in soil on non-deforested and deforested land after subtracting any losses at the end of the reporting year (for a given afforestation year); assumption of organic soil type (5) and formerly arable land use.
carbon_after_ara5	Carbon in soil on non-deforested and deforested land after subtracting any losses at the end of the reporting year (for a given afforestation year); assumption of organic soil type (5) and formerly arable land use.
carbon_defor_ara5	Carbon in soil on deforested land after subtracting any losses at the end of the reporting year (for a given afforestation year); assumption of organic soil type (5) and formerly arable land use.

Column name	Description
carbon_before_pas1	Carbon in soil on non-deforested and deforested land at the end of the reporting year (for a given afforestation year); assumption of sand soil type (1) and formerly pasture land use.
carbon_after_pas1	Carbon in soil on non-deforested and deforested land after subtracting any losses at the end of the reporting year (for a given afforestation year); assumption of sand soil type (1) and formerly pasture land use.
carbon_defor_pas1	Carbon in soil on deforested land after subtracting any losses at the end of the reporting year (for a given afforestation year); assumption of sand soil type (1) and formerly pasture land use.
carbon_before_pas2	Carbon in soil on non-deforested and deforested land at the end of the reporting year (for a given afforestation year); assumption of loam soil type (2) and formerly pasture land use.

Column name	Description
carbon_after_pas2	Carbon in soil on non-deforested and deforested land after subtracting any losses at the end of the reporting year (for a given afforestation year); assumption of loam soil type (2) and formerly pasture land use.
carbon_defor_pas2	Carbon in soil on deforested land after subtracting any losses at the end of the reporting year (for a given afforestation year); assumption of loam soil type (2) and formerly pasture land use.
carbon_before_pas3	Carbon in soil on non-deforested and deforested land at the end of the reporting year (for a given afforestation year); assumption of clay soil type (3) and formerly pasture land use.
carbon_after_pas3	Carbon in soil on non-deforested and deforested land after subtracting any losses at the end of the reporting year (for a given afforestation year); assumption of clay soil type (3) and formerly pasture land use.

Column name	Description
carbon_defor_pas3	Carbon in soil on deforested land after subtracting any losses at the end of the reporting year (for a given afforestation year); assumption of clay soil type (3) and formerly pasture land use.
carbon_before_pas4	Carbon in soil on non-deforested and deforested land at the end of the reporting year (for a given afforestation year); assumption of organoclay soil type (4) and formerly pasture land use.
carbon_after_pas4	Carbon in soil on non-deforested and deforested land after subtracting any losses at the end of the reporting year (for a given afforestation year); assumption of organoclay soil type (4) and formerly pasture land use.
carbon_defor_pas4	Carbon in soil on deforested land after subtracting any losses at the end of the reporting year (for a given afforestation year); assumption of organoclay soil type (4) and formerly pasture land use.

Column name	Description
carbon_before_pas5	Carbon in soil on non-deforested and deforested land after subtracting any losses at the end of the reporting year (for a given afforestation year); assumption of organic soil type (5) and formerly pasture land use.
carbon_after_pas5	Carbon in soil on non-deforested and deforested land after subtracting any losses at the end of the reporting year (for a given afforestation year); assumption of organic soil type (5) and formerly pasture land use.
carbon_defor_pas5	Carbon in soil on deforested land after subtracting any losses at the end of the reporting year (for a given afforestation year); assumption of organic soil type (5) and formerly pasture land use.
carbon_after_woodfuel_wp	Carbon in woodfuel from non-deforested areas for the reporting year / afforestation year combination
carbon_after_unextracted_material_wp	Carbon in extractable harvest material which is left on site (e.g. branches) from non-deforested areas for the reporting year / afforestation year combination

Column name	Description
carbon_after_particleboard_longlived_wp	Carbon in long-lived particleboard wood products from non-deforested areas for the reporting year / afforestation year combination
carbon_after_particleboard_shortlived_wp	Carbon in short-lived particleboard wood products non-deforested areas for the reporting year / afforestation year combination
carbon_ after_pallet_fencing_wp	Carbon in pallet and fencing wood products from non-deforested areas for the reporting year / afforestation year combination
carbon_after_paper_ephemeral_wp	Carbon in ephemeral paper wood products from non-deforested areas for the reporting year / afforestation year combination
carbon_after_paper_shortlived_wp	Carbon in short-lived paper wood products from non-deforested areas for the reporting year / afforestation year combination
carbon_after_paper_longlived_wp	Carbon in long-lived paper wood products from non-deforested areas for the reporting year / afforestation year combination
carbon_after_structural_wp	Carbon in structural timber wood products from non-deforested areas for the reporting year / afforestation year combination

Column name	Description
carbon_defor_woodfuel_wp	Carbon in woodfuel from deforested areas for the reporting year / afforestation year combination
carbon_defor_unextracted_material_wp	Carbon in extractable harvest material which is left on site (e.g. branches) from deforested areas for the reporting year / afforestation year combination
carbon_defor_particleboard_longlived_wp	Carbon in long-lived particleboard wood products from deforested areas for the reporting year / afforestation year combination
carbon_defor_particleboard_shortlived_wp	Carbon in short-lived particleboard wood products from deforested areas for the reporting year
carbon_defor_pallet_fencing_wp	Carbon in pallet and fencing wood products from deforested areas for the reporting year / afforestation year combination
carbon_defor_paper_ephemeral_wp	Carbon in ephemeral paper wood products from deforested areas for the reporting year / afforestation year combination
carbon_defor_paper_shortlived_wp	Carbon in short-lived paper wood products from deforested areas for the reporting year / afforestation year combination

Column name	Description
carbon_defor_paper_longlived_wp	Carbon in long-lived paper wood products from deforested areas for the reporting year / afforestation year combination
carbon_defor_structural_wp	Carbon in structural timber wood products from deforested areas for the reporting year / afforestation year combination

Annual carbon stocks

This file has the nearly the same format as the ghg_inventory_ouput file (Table 2), but values are summarised within each reporting year only. There is, therefore, only one value per reporting year in this file and no afforestation year column.

Single stand annual carbon

This file is only produced as output for single-stand runs. It has the same format of results as the ghg_inventory_output file but with the stand's metadata (e.g., species, management etc.) included in the output. These additional metadata columns are shown in Table 3.

Table 3. Description of metadata columns in the single stand annual carbon output file.

Column name	Description
Year	Years since stand afforested
Rotation	Rotation number
Species	Tree species (code)
wp_species	Mapped tree species used to assign wood product allocation (code). See CARBINE-R Technical Guide.
Yieldclass	Yield class of stand

Column name	Description
management	Management code of stand (1-4)
transition_period	Transition period
species_full	Tree species (full common name)
leaf_type	Conifer or broadleaf
tree_type	Evergreen or deciduous
wood_type	Softwood or hardwood
top_height	Top height of the stand in the reporting year
num_trees	Number of standing live trees in the stand in the reporting year

Multi-stand results by stand

For multi-stand outputs in the above outputs the carbon values across different stand prescriptions are aggregated within the same reporting year. In this output named 'multi_stand_results_by_stand.csv', the stand prescription remains separate and identifiable by a 'stand_id' column (located at the end of file). This file otherwise has the same column heading format as the ghg inventory output file.

Graphs

At the end of a CARBINE-R model run, a number of graphs are generated using the 'annual_carbon_stocks' dataframe. These provide a quick visualisation of the results, allowing the user to check they look as expected. These graphs are saved into the output folder. For test case runs, they will be in a subfolder with the test case number; for other run types they will be saved in a subfolder with the project name as specified in the config file.

1.4.2. Intermediate outputs

In addition to the main CARBINE-R outputs described above, the results of intermediate steps of the CARBINE-R model, such as the turnover values, are

optional outputs. For multi-stand runs, these will only show the outputs for the last stand run. These outputs can be specified to be generated or not in the 'output_options' sheet in the config file. See section 3.3 for more guidance on selecting intermediate graph and data outputs.

1.4.3. Test case additional outputs

Test cases also output results from individual modules. For multi-stand runs, these will only show the outputs for the last stand run. These outputs are:

- Soil results (ara 1 to 5 & pas 1 to 5): Soil results for forests with either arable ('ara') and pasture ('pas') prior land uses for five different soil types (sand, loam, clay, organoclay & organic).
- Deadwood: Carbon stocks in deadwood pool
- Harvest: Carbon stocks in harvested trees
- Litter: Carbon stocks in the litter pool
- Tree before thin: Carbon in trees before subtracting any losses on non-deforested land in that reporting year
- Tree main crop: Carbon in trees after subtracting losses (turnover, mortality and/or harvest) on non-deforested land in that reporting year
- Vol_harvested: Total volume of trees harvested in that year (default assumption is that only stems are harvested).
- Wood_products_carbon: Carbon in wood products from harvested trees

Other intermediate outputs as data files or graphs can be selected for output in the config file (see section 3.3).

1.5. Model diagram

The main inputs include: i) a config file where run type, parameters and output options are selected; ii) a stand management prescription file (known as the 'spplist'); iii) one or more area files which delineate afforestation years and planting

areas; and iv) multiple parameter files. These inputs first enter the regional scale modules which include the start-up scripts which prepare and format parameter and management prescriptions for use in the M1 growth model. The output of this is one or more formatted stand prescriptions, which are entered into the stand level modules. These modules start with the M1 growth model and estimate carbon stocks for that tree stand. The one or more carbon stock results for each stand are then returned to the regional scale modules, where results are aggregated and formatted for output. The outputs include this main aggregated carbon stock file, as well as optional stand level results and graphs.

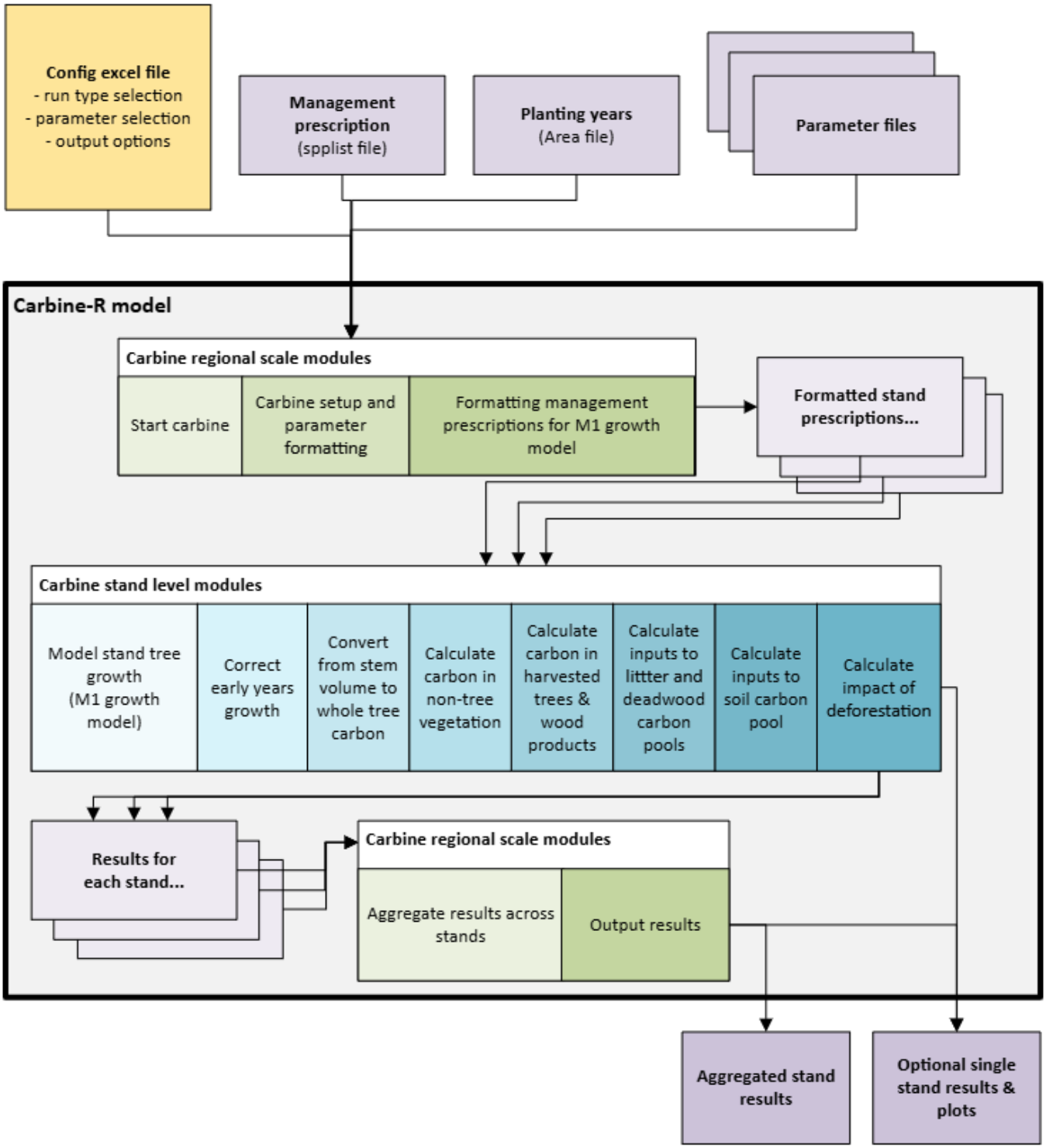


Figure 1. A simplified overview of the CARBINE-R model structure, including inputs and main calculating steps.

2. Accessing & installing CARBINE-R

2.1. Software requirements

CARBINE-R runs on the open-source software known as 'R'. We recommend running 'R' using an interface called 'RStudio'. CARBINE-R is contained as an 'RStudio project'. The project folder contains all required input files for a CARBINE-R run. The project folder acts as the 'home' directory for the project and all file paths direct to this folder. Therefore, there should be no need to update any file paths, unless you are changing default parameter inputs (see section 3.4). This also means that the folder structure and location of inputs should not be changed for default runs; otherwise, they will not be found by the model.

2.2. Access

CARBINE-R is currently only accessible on request from the Mensuration, Growth and Yield science group within Forest Research. To request access to the model, please complete a 'CARBINE access agreement' and email it to 'ghgi@forestresearch.gov.uk'.

2.3. Installation

2.3.1. Installing R, RStudio and Rtools

R can be installed from the Comprehensive R Archive Network (CRAN) (v4.4.2 or newer is required).

Rtools is needed to install bespoke R packages integral to the running of CARBINE-R (M1R and ScotiaR). It is important to install the same version of Rtools (i.e., v4.4) as the version of R (e.g., v4.4.2).

We recommend installing and running the project through RStudio, which is a commonly used integrated development environment (IDE) for R. The guidance written here is based on using RStudio.

2.3.2. Setting up the R environment (renv)

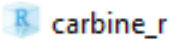
Installing renv package

If this is your first time running R or you don't have renv installed, you'll need to install it. Run the following command in the R console:

```
install.packages('renv')
```

If you already have renv installed, you can skip this step.

Using renv to generate R environment

Open the R-project, either by opening the 'carbine_R' R project file (

 ), which will open in RStudio, or by opening RStudio and then opening the R project. The RStudio console should look like Figure 2.

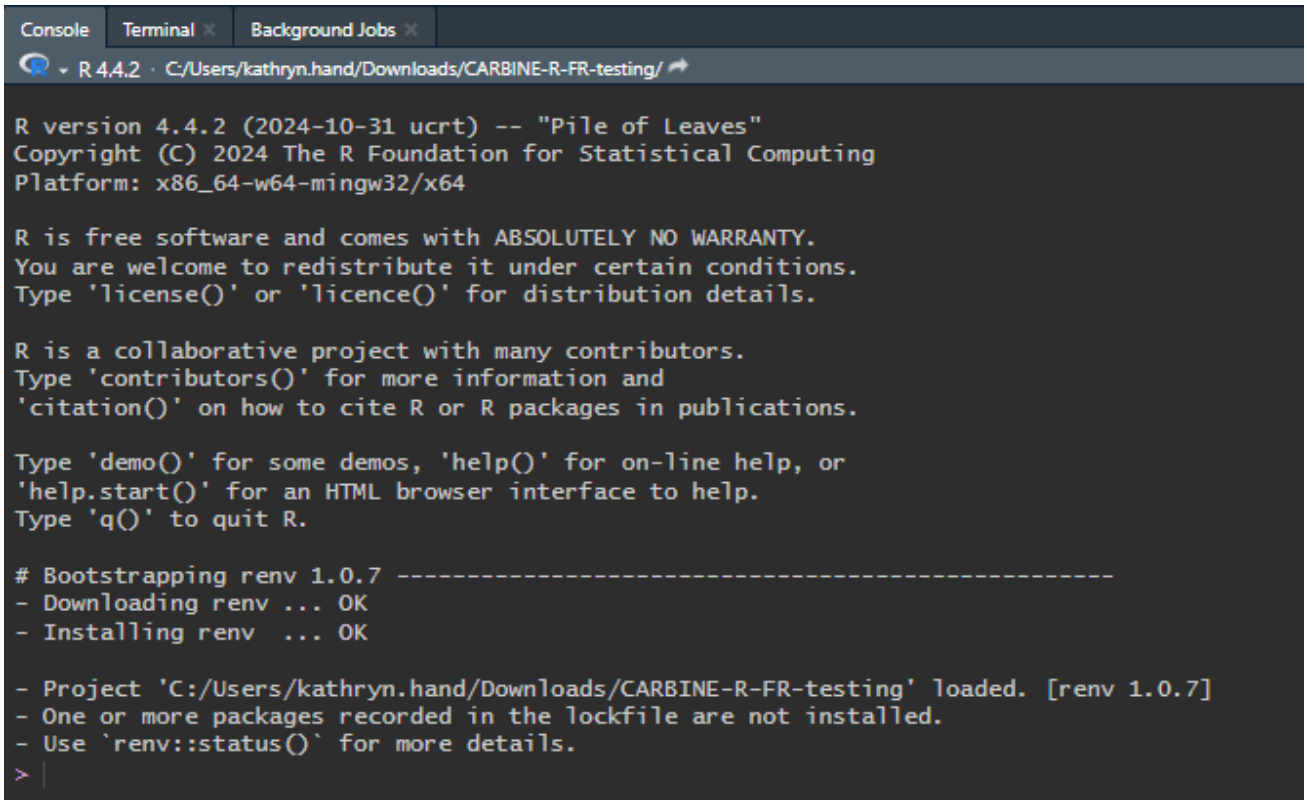


Figure 2. RStudio Console showing initial setup upon first opening of the project.

CARBINE-R uses various packages, which are mostly open source and are available to download from online repositories such as CRAN. Two packages, M1R and ScotiaR, are bespoke packages made for CARBINE-R and are provided with the main CARBINE-R R project. To prevent changes to R or package versions affecting the output of CARBINE-R, package management within the CARBINE-R project has been set up with the renv package. This package reproduces the environment (R and package versions) used in the source version of CARBINE-R on a user's machine, so that the CARBINE-R run environment is maintained.

Upon first installation as in Figure 2, the renv package will have already installed itself, searched the local machine for the required packages, and likely found that some packages are missing. The command 'renv::status()' can be used to view which packages are missing. Running the **'renv::restore()'** command will show what package changes need to be made, and R will ask for confirmation to proceed to download and install these packages. **Enter 'Y' to continue.** It may take a few minutes to download and install all packages.

If you encounter errors at this stage, please check the Troubleshooting & FAQs section for help.

3. Running CARBINE-R

This section explains how the CARBINE-R model can be run and the different options for how to run the model.

Section 3.1 explains the general setup using the config file.

Section 3.2 overviews three different methods of running CARBINE-R:

- Test case run
- GHG inventory run
- Bespoke stand prescription run

Section 3.3 details how to select desired data and graph outputs.

Section 3.4.1 and 3.4.2 detail how parameter values can be altered.

Section 3.5 describes how weather data can be altered.

3.1. General setup

There are two main steps in setting up a CARBINE-R model run:

3.1.1. Setting up the config file

The config file ('0_carbine_config.xlsx') contains the settings for a CARBINE-R run. This file needs to be completed before a model run can take place. The full description of settings within the config file are described in section 1.3.

A main role of the config file is to set the type of CARBINE model run. The options for run types and how to set up these up within the config file are described in section 3.2.

3.1.2. Running the 'carbine_start.R' script

Once the config file has been finalised, saved, and closed, open the 'carbine_r' project file: carbine_r

This will open RStudio. Now open the 'carbine_start.R' script, which is located in the 'R' folder. You can locate this within RStudio's bottom right-hand pane, under the 'Files' tab (Figure 3). The script will open in the top left-hand 'console' pane of RStudio.

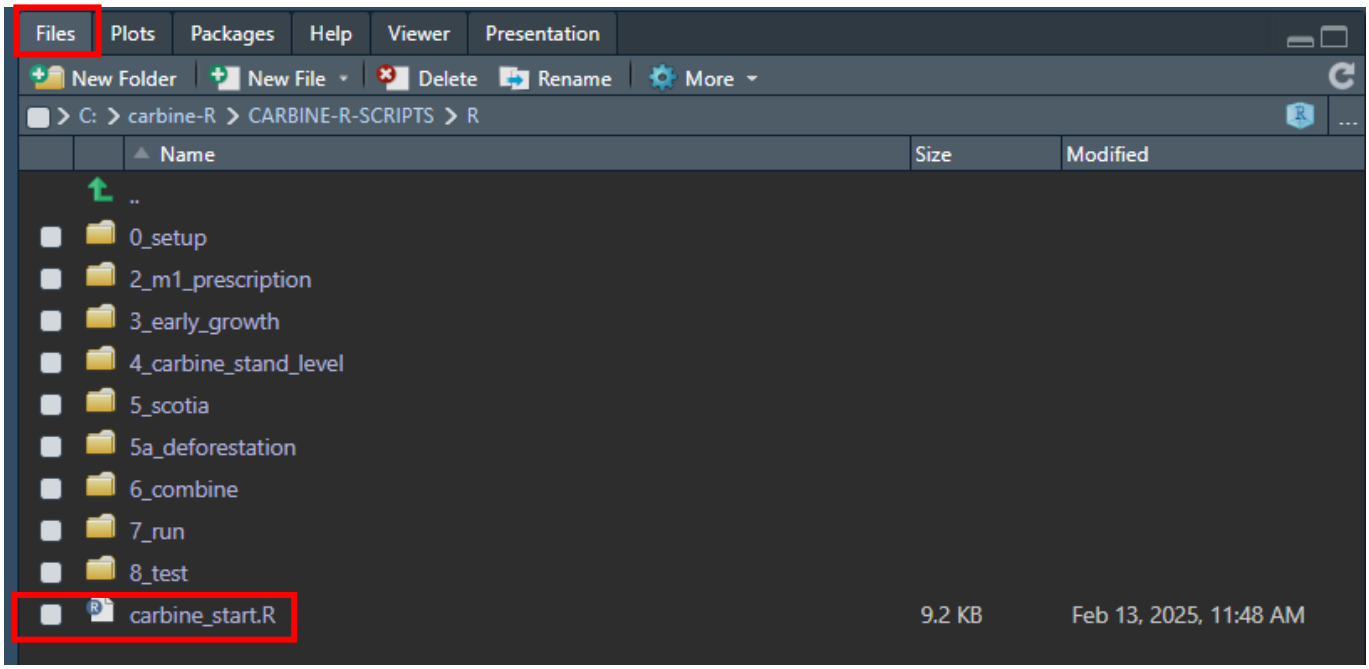


Figure 3. Location of the "R/carbine_start.R" script in the 'Files' pane in RStudio.

The 'carbine_start.R' script can be run by clicking the 'Source' button on the top right-hand corner of the of the script (Figure 4).

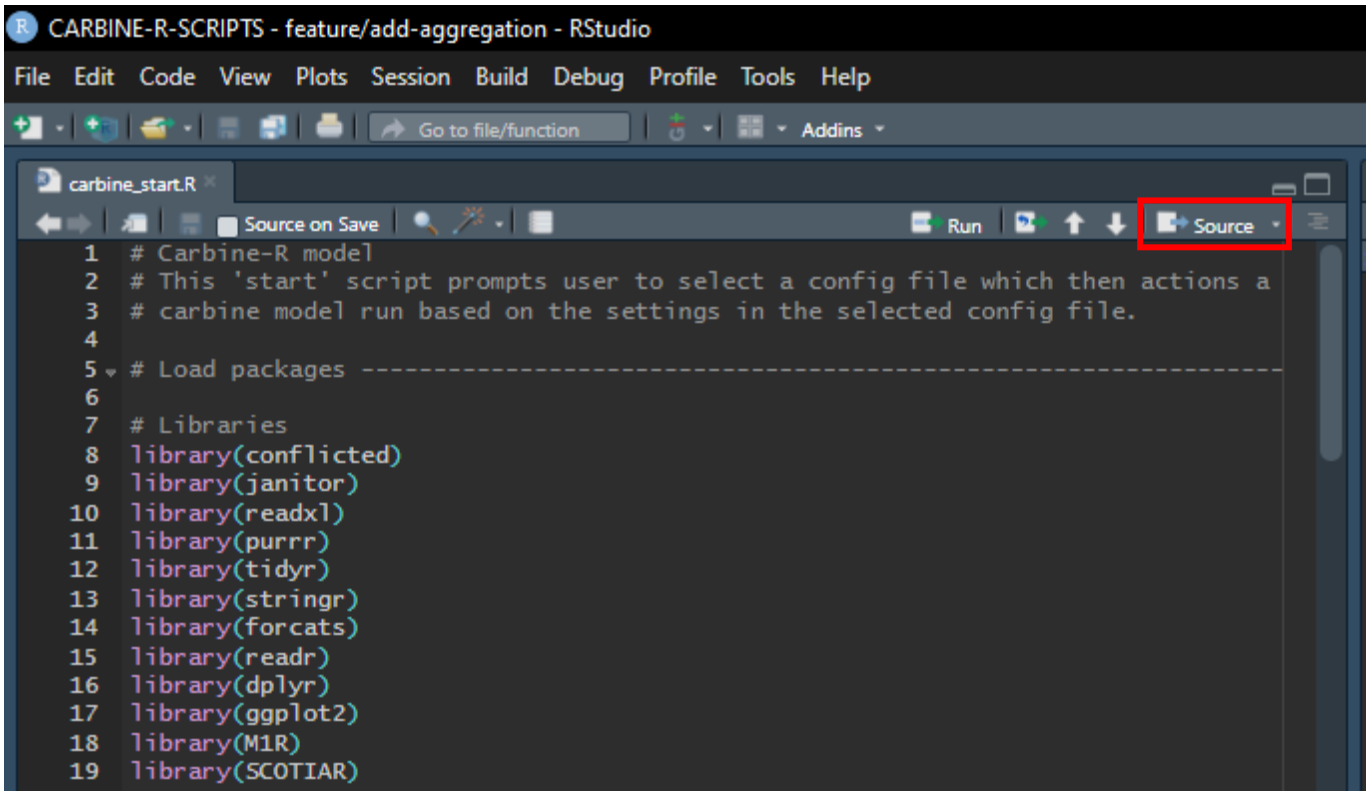


Figure 4. Run the "R/carbine_start.R" script using the 'Source' button.

3.2. Run types

3.2.1. Test case runs

A number of test cases are supplied along with the CARBINE-R project. These can be used as dummy runs as well as 'master' files to compare the impact of any changes to CARBINE-R code or inputs.

A test case run can be selected to be run using the config file. Selecting 'test case' from the 'run_type' field will generate a new option to select the test case number. Once selected, save the config file. You can save multiple versions of the config file with different names.

Alternatively, all the test cases can be run at once using the 'R/8_test/run_test_cases.R' script. Here, the desired selection of test cases can be set by changing the numbers entered into the command 'test_case_numbers' at line 32.

Test case results are saved in the output folder, in a subfolder with the test case number.

Table 4. Description of test cases provided with CARBINE-R project.

Test case number	Single- or multi-stand	Description
1	Single-stand	A stand prescription with 8 management transitions, starting with Scots pine for the first five management periods under varying thin or no thin management types and varying rotation lengths, to oak under varying thin and no thin management types and varying rotation lengths. Single afforestation year of 1500, area of 1 ha and England weather data used.
2	Single-stand	A stand prescription with 4 management transitions. All management transitions are oak stands, but with varying management (thin, fell; to LISS; to no thin, fell; to LISS again). Single afforestation year of 1500, area of 1 ha and England weather data used.
3	Single-stand	A stand prescription with one management transition, from a Sitka spruce stand with no thinning for 80 year rotation to a Sitka spruce stand with no thinning for a 100 year rotation. Single afforestation year of 1500, area of 1 ha and England weather data used.
4	Single-stand	The same stand prescription and area as test case 1, but with deforestation occurring
5	Single-stand	The same stand prescription and area as test case 2, but with deforestation occurring
6	Single-stand	The same stand prescription and area as test case 3, but with deforestation occurring

Test case number	Single- or multi-stand	Description
7	Single-stand	The same stand prescription as test case 1, but with an afforested area of 500 ha and deforestation occurring
8	Single-stand	The same management prescription as test case 1, but with deforestation occurring, an area of 500 ha and an afforestation year of 1600
9	Single-stand	The same stand prescription as test case 1, but with an afforestation year of 1600
10	Single-stand	A stand prescription with no transitions in management occurring. The tree species is Scots pine under an unchanging management of no thinning, fell regime and 100 year rotation length. A single afforestation year of 1600, area of 1 ha and England weather data used.
11	Single-stand	A stand prescription with no transitions in management occurring. The tree species is beech under an unchanging management prescription of no thinning, fell regime and a 273 year rotation length. A single afforestation year of 1600, area of 1 ha and England weather data used.
12	Single-stand	A stand prescription with no transitions in management p occurring. The tree species is poplar under an unchanging management regime of no thinning, fell regime and a 25 year rotation length. A single afforestation year of 1600, area of 1 ha a different weather data used.

Test case number	Single- or multi-stand	Description
13	Multi-stand	Stand prescriptions , where each prescription has no transitions in the assigned management prescription. Each stand prescription is composed of different tree species and different yield class and with varying rotation lengths, but all are managed under no thinning, fell regimes. Prescriptions may have different afforestation years and planting areas.
14	Multi-stand	Multiple stand prescriptions, where each prescription has no transitions in the assigned management prescription. Each prescription is composed of a different tree species and different yield class and with varying rotation lengths, but all are managed under no thinning, fell regimes. Prescriptions may have different afforestation years and planting areas.
15	Multi-stand	Multiple stand prescriptions, where each prescription has no transitions. Each prescription is composed of different species of different yield classes and with varying rotation lengths, but all are managed under thin, fell regimes. Prescriptions may have different afforestation years and planting areas.
16	Multi-stand	Multiple stand prescriptions, where each prescription has no transitions. Each prescription is composed of different species of different yield classes and with varying rotation lengths, but all are managed under thin, fell regimes. Prescriptions may have different afforestation years and planting areas.

Test case number	Single- or multi-stand	Description
17	Multi-stand	Multiple stand prescriptions, where each prescription has no transitions. Each prescription stand is composed of different species of different yield classes and with varying rotation lengths. All are managed under an edge case management setup of thin, no fell. Prescriptions may have different afforestation years and planting areas.
18	Multi-stand	Multiple stand prescriptions, where each prescription has no transitions. Each prescription is composed of different species of different yield classes and with varying rotation lengths. All are managed under an edge case management setup of thin, no fell. Prescriptions may have different afforestation years and planting areas.
19	Multi-stand	Multiple stand prescriptions, where each prescription has no transitions. Each prescription is composed of different species of different yield classes, but all are managed under LISS regimes. Prescriptions may have different afforestation years and planting areas.
20	Multi-stand	Multiple stand prescriptions, where each prescription has no transitions. Each prescription is composed of different species of different yield classes, but all are managed under LISS regimes. Prescriptions may have different afforestation years and planting areas.

Test case number	Single- or multi-stand	Description
21	Multi-stand	Multiple stand prescriptions, where each prescription has no transitions. Each prescription is composed of different species of different yield classes, but all are managed under LISS regimes. Prescriptions may have different afforestation years and planting areas.

3.2.2. GHG inventory run

The CARBINE-R model runs a UK GHG inventory over eight runs (Table 5), where each run computes the carbon stocks in one nation and one tree taxon, i.e., broadleaf in England, conifer in England, etc. Given that running CARBINE for an entire nation's forest can be lengthy, they are set up to be run independently, i.e., so that eight instances of CARBINE-R can be run simultaneously.

A GHG inventory run is set up using the config file. In the project_info sheet, select 'GHG inventory' from the drop-down list for the 'run_type' option. This will trigger additional boxes to appear for the country and leaf type to be selected. The corresponding weather 'met_file' will also need to be selected.

Currently CARBINE-R is released with data for Northern Ireland (2024 release) only to demonstrate a GHG inventory run. Note that this can take many hours to run. Full inventory datasets will be provided after the current year's inventory has been published using the CARBINE-R model (sometime after April 2026).

The results of GHG inventory runs will be saved in the outputs folder, in a subfolder with the project name defined in the selected config file.

Table 5. Setup of folders for a full GHG inventory run.

Run number	Country	Tree type
1	England	Broadleaf
2	England	Conifer
3	Northern Ireland	Broadleaf
4	Northern Ireland	Conifer
5	Scotland	Broadleaf
6	Scotland	Conifer
7	Wales	Broadleaf
8	Wales	Conifer

3.2.3. Bespoke stand prescriptions

Not yet fully implemented in model

A user can define their own single stand management prescriptions using the 'Spplist_template.xlsm' file. This is located in:

'\input\management_prescription\user_defined_files'

The Spplist_template file provides instructions on how to write a management prescription. This culminates in generating a spplist sheet which is then saved as a .csv file type in the same folder as the spplist template.

This user-defined spplist can be set to run using the config file.

Currently, it is only possible to run single-stand bespoke management prescriptions.

3.3. Selecting data and graph output options

In addition to the main CARBINE outputs, data files and graphs of intermediate stages of the model can be selected for output. This can be done by simply changing the 'Y'/'N' values in the 'output_options' sheet for either the 'data_output' and/or 'plot_output' columns in the configfile.

3.4. Altering parameters

Please see the technical guide for a detailed description of each parameter and its default values used in the model.

3.4.1. Parameter datasets

CARBINE uses a wide array of parameters which define the settings under which the CARBINE-R model is run. Parameters with a lot of values are held in named .csv files, such as weather information or decay rates by species. Other parameters are simpler (e.g. fallow period length) and are read in as a single value from the

config file. These parameters are currently set to the default values used in the GHG inventory, but many can be altered if desired by the user.

Parameters which are held in named .csv files are listed in the 'parameter_inputs' sheet of the config file. This sheet lists each parameter and the file path where the parameter dataset is stored. To alter a parameter dataset, copy the default dataset from its location and move to the 'input/parameters/alternative_parameters' folder. You can either leave it in this folder or create a subfolder for it (if you choose the latter, you need to update the file path in the 'alternative file location' column of the config file (column H)). You also need to change the input in the 'use ghgi default inputs' value (column E) from 'Y' to 'N'. Note that the 'parameter_inputs' sheet is protected except for those cells which should be edited to alter parameters as described above.

Single value parameters are read in from a sheet in the config file called 'default_param_options'. The parameters listed here are:

Overwrite fallow period

Not yet implemented in code

Set default LISS overlap

The LISS overlap period is the number of years in which two consecutive LISS (low impact silvicultural system) rotations overlap each other. The default value is 30, but this can be overwritten within the 'default_param_options' sheet of the config file.

Set no go period

When a stand of trees approaches the clearfell rotation age, a scheduled thinning that would be very close to the clearfelling event may not be carried out (so as to wait for the harvest at clearfelling). The no go period is the number of years before a clearfelling event during which thinning is avoided. The default value is 0 years (meaning the value is effectively not set, and a scheduled thinning can be carried

out just 1 year before the clearfelling event), but this can be overwritten within the 'default_param_options' sheet of the config file.

Set thinning cycle

The thinning cycle is the number of years between consecutive thinning events. The default is 5 years, but this can be overwritten within the 'default_param_options' sheet of the config file.

Fine root biomass maximum

The 'fine root biomass maximum' defines a value for the maximum biomass (oven dried tonnes per ha) of fine roots that can accumulate. The default is set at 4 odt ha^{-1}.

Override litter turnover rates

Not yet implemented in code

Override ground preparation value

Not yet implemented in code

Override prior land use

Not yet implemented in code

3.5. Weather data

Weather data in the CARBINE model affects the decay rate of litter and deadwood pools and the soil water balance. It does not affect the growth or survival of trees. There are four default weather inputs in CARBINE-R, one for each UK nation.

Location-specific weather data can be added. This must follow the format shown in Table 6, with mean temperature and total precipitation given for each month. The file should be saved as a .csv file in the 'input/weather' folder, within its own named folder. The name of the folder will need to be specified in the config file.

Table 6. Example format of a weather data file.

country	location	latitude	Month	mean_temp	precipitation
England	Kielder	55.226	1	2.1	117.6
England	Kielder	55.226	2	1.9	92.2
England	Kielder	55.226	3	4.25	94.6
England	Kielder	55.226	4	6.9	75.9
England	Kielder	55.226	5	11.3	76.7
England	Kielder	55.226	6	15.45	95.5
England	Kielder	55.226	7	18.6	102.5
England	Kielder	55.226	8	18.15	116.2
England	Kielder	55.226	9	14.95	107.7
England	Kielder	55.226	10	10.4	130.6
England	Kielder	55.226	11	2.2	118
England	Kielder	55.226	12	2.35	125.4

4. Model limitations

4.1. Lack of disturbance impacts

The CARBINE model, in its current form, cannot explicitly model the impact of disturbances (such as pest and disease outbreaks, or climate change) on tree growth. This is an area Forest Research is keen to develop and improve.

4.2. Large-scale focus

The CARBINE model was developed for large-scale (i.e. national) analyses of forest carbon. The tree species, yield classes and management prescriptions represented in the model are intended to capture the main sources of variation observed in UK forests. While this does not cover all the detailed variation in UK tree species,

growth rates and management practices, it does represent those most commonly observed in the UK.

Biomass expansion factors applied in CARBINE (see Section 4.4), rather than allometric relationships, give robust estimates across larger scales but are less reliable at smaller scales.

Only five soil classes are represented in CARBINE. This means that results for individual stands (small scales) will have higher uncertainties compared to the overall results from large-scale projections covering many different stands.

4.3. Plantation forestry focus

The model was initially developed for commercial forestry using growth rates developed from these types of forests. This approach has embedded characteristics of these forest systems into the model, such as assuming single species, single age stands and a standard planting density for each tree species. This means the model is limited in its ability to accurately model more complex stands of trees (such as mixed species or mixed age forests) or other forest systems (such as agroforestry). While CARBINE can currently model mixed species and mixed age stands, this required compartmentalising each stand into monoculture blocks and modelling each block separately. The model will therefore not account for any of the interactions between different species and the effects of this on their growth. This is an area where Forest Research are keen to develop and implement improvements to better represent these stands.

4.4. Whole tree biomass estimation

In the current implementation of CARBINE, whole tree biomass is estimated using biomass expansion factors. This is a commonly used approach, which is robust but does not vary with tree age or size, and so may underestimate biomass in young/small trees and overestimate in older stands/bigger trees. Forest Research is looking to improve this using newly developed allometric equations which allow

whole tree biomass calculations to vary with tree size. This could help mitigate the biases identified above.

4.5. Parameter data limitations

CARBINE requires a number of parameters to model carbon stocks. Parameters have been selected from the best available information; however, for some areas, limited information is available. Sometimes this has necessitated using values from other nations or making assumptions. There are opportunities to improve parameter values in CARBINE in future, either by collecting new data and/or by disaggregating values so that they are specific to different tree species, components, and/or ages.

5. Troubleshooting & FAQs

5.1. Getting 'Error in library(conflicted)' error message

If you are receiving the following error message:

"Error in library(conflicted) : there is no package called 'conflicted'"

then you still need to run the 'renv::restore()' command to set up the R environment before CARBINE-R can run. Please see section 2.3.2 for full instructions.

5.2. Getting error messages from renv::restore() command

This may be due to organisational restrictions on downloading packages from the internet, which will lead to error messages such as the one below:

"LoadLibrary failure: This program is blocked by group policy. For more information, contact your system administrator.

Calls: <Anonymous> ... namespaceImport -> loadNamespace -> library.dynam -> dyn.load -> inDL

Execution halted

ERROR: lazy loading failed for package 'M1R'

* removing 'C:/carbine-R/CARBINE-R-SCRIPTS/renv/staging/1/M1R'

install of package 'M1R' failed [error code 1]"

If you encounter an issue such as this, please get in touch with us (ghgi@forestresearch.gov.uk). We can supply you with a template '.Renviron' file which we use at Forest Research to specify R package file paths to comply with

organisational permissions. You may need to speak to your own IT department to understand how these paths need updating to comply with your organisation's specific setup.

6. Glossary & Abbreviations

Table 7. Glossary of technical terms and abbreviations used in the text.

Name	Definition	Source
Age	Stand age in years, from age 0 (planting year) onwards.	
Afforestation year	The year in which direct human-induced conversion of land that has not been forested in the recent past to forested land occurs through planting, seeding and/or the human-induced promotion of natural seed sources, e.g. a transition from pasture or arable land to forest land.	After Matthews, R., Mortimer, N, Lesschen, J-P., Lindroos, T.J., Sokka, L., Morris, A., Henshall, P., Hatto, C., Mwabonje, O., Rix, J., Mackie, E. and Sayce, M. (2015) Carbon impact of biomass consumed in the EU: quantitative assessment. Final project report, project: DG ENER/C1/427. Forest Research: Farnham.

Name	Definition	Source
Basal area	The overbark cross-sectional area of the stem of alive tree, measured at 1.3 m above ground-level, and given in sq metres. The sum of the basal areas of all the trees in an area of woodland expressed on a per hectare basis gives basal area per hectare.	Matthews, R.W., Jenkins, T.A.R., Mackie, E.D. and Dick, E.C. (2016). Forest Yield: A handbook on forest growth and yield tables for British forestry Forestry Commission, Edinburgh. i–iv + 1–92pp.
Clearfell	The periodic harvesting of trees in a woodland, involving the complete or near-complete removal of standing trees for commercial utilisation.	Matthews, R.W., Jenkins, T.A.R., Mackie, E.D. and Dick, E.C. (2016). Forest Yield: A handbook on forest growth and yield tables for British forestry Forestry Commission, Edinburgh. i–iv + 1–92pp.
Crown	The branches and foliage of a tree.	Matthews, R.W., Jenkins, T.A.R., Mackie, E.D. and Dick, E.C. (2016). Forest Yield: A handbook on forest growth and yield tables for British forestry Forestry Commission, Edinburgh. i–iv + 1–92pp.

Name	Definition	Source
Cumulative volume production	The total production of timber volume from a stand up to a given year in the stand's development. It is calculated as the standing volume per hectare attained by a forest stand in a given year plus the sum of per hectare volumes removed as thinnings up to that year.	Matthews, R.W., Jenkins, T.A.R., Mackie, E.D. and Dick, E.C. (2016). Forest Yield: A handbook on forest growth and yield tables for British forestry Forestry Commission, Edinburgh. i–iv + 1–92pp.
DBH	The diameter on the main stem of a tree at 'breast height', i.e., 1.3 m from ground level.	Matthews, R.W. and Mackie, E.D. (2006). Forest Mensuration: a handbook for practitioners. Forestry Commission, Edinburgh. i–vi + 1–330pp.
Deforestation	The direct human-induced conversion of forested land to non-forested land.	UNFCCC, 2001. Decision /CP.7: The Marrakesh Accords (Available at: www.unfccc.int/ cop7/documents /accords_draft.pdf).

Name	Definition	Source
Fallow period	A length of time in between two rotations when trees are absent from the site (minimum length of one growing season)	
Git	Git is a widely used version control system and is used for version control of the CARBINE-R model.	https://github.com/git-guides
ha	Hectare, unit of area of 10 000 m^2, equivalent to 100 m × 100 m (1 ha = 2.47 acres)	Matthews, R.W. and Mackie, E.D. (2006). Forest Mensuration: a handbook for practitioners. Forestry Commission, Edinburgh. i–vi + 1–330pp.

Name	Definition	Source
Intermediate thinning	A type of thinning (see *Thinning*) which involves the removal of most of the suppressed and sub-dominant trees, and also the opening up of the canopy by breaking up groups of competing dominant and co-dominant trees. This encourages the development of the remaining trees and leaves an open and fairly uniform stand. The volume of timber removed at a thinning is known as the thinning yield and typically calculated as 5 × 0.7 × yield class, where 5 is the default number of years between thins, 0.7 is the marginal thinning intensity (see *Marginal thinning intensity*) and yield class is the yield class of the trees in question.	Matthews, R.W., Jenkins, T.A.R., Mackie, E.D. and Dick, E.C. (2016). Forest Yield: A handbook on forest growth and yield tables for British forestry Forestry Commission, Edinburgh. i–iv + 1–92pp.

Name	Definition	Source
LISS	'Low Impact Silvicultural Systems', are forest management systems intended to reduce impacts, when compared to clearfell systems. LISS includes continuous cover forestry (CCF). Large scale clearfelling is avoided in these management systems. Thinning practice may vary but typically involves gradual removal of the existing stand of trees. At some point in the life cycle of the stand, new trees of the next rotation are planted or regenerate and grow in the space created by the thinnings.	Forestry Commission (2008) Managing Continuous Cover Forests. Operational Guidance Booklet No. 7. Forestry Commission, Edinburgh.

Name	Definition	Source
MAI	A measure of the volume productivity of forest stands (usually even-aged). Mean annual increment is the average rate of cumulative volume production up to a given year. In even-aged stands, it is calculated by dividing cumulative volume production by age.	Matthews, R.W., Jenkins, T.A.R., Mackie, E.D. and Dick, E.C. (2016). Forest Yield: A handbook on forest growth and yield tables for British forestry Forestry Commission, Edinburgh. i–iv + 1–92pp.
Management prescription	The combination of initial planting spacing, thinning regime, and age of felling applied to a stand of trees.	Matthews, R.W., Jenkins, T.A.R., Mackie, E.D. and Dick, E.C. (2016). Forest Yield: A handbook on forest growth and yield tables for British forestry Forestry Commission, Edinburgh. i–iv + 1–92pp.

Name	Definition	Source
Marginal Thinning Intensity (MTI)	The maximum thinning intensity which can be maintained without causing loss of volume production. This is equivalent to 70% of the yield class each year, when thinning begins at the marginal thinning age.	Matthews, R.W., Jenkins, T.A.R., Mackie, E.D. and Dick, E.C. (2016). Forest Yield: A handbook on forest growth and yield tables for British forestry Forestry Commission, Edinburgh. i–iv + 1–92pp.
Multi-stand run	A CARBINE-R model run involving more than one stand prescription, as listed in the spplist file. Outputs of multi-stand runs are summed across different stand prescriptions in the same reporting and afforestation years.	
Neutral thinning	A type of thinning in which the size distribution of the thinnings is identical to the trees left standing.	Matthews, R.W., Jenkins, T.A.R., Mackie, E.D. and Dick, E.C. (2016). Forest Yield: A handbook on forest growth and yield tables for British forestry Forestry Commission, Edinburgh. i–iv + 1–92pp.

Name	Definition	Source
Odt	Oven-dry tonne. Unit of mass. When applied to wood, it represents the mass of oven-dried wood in tonnes, not including the mass due to the moisture content of the wood (which may vary considerably).	Matthews, R.W., Jenkins, T.A.R., Mackie, E.D. and Dick, E.C. (2016). Forest Yield: A handbook on forest growth and yield tables for British forestry Forestry Commission, Edinburgh. i–iv + 1–92pp.
Overbark/underbark	Applies to the volume or diameter of wood including or excluding the bark.	Matthews, R.W. and Mackie, E.D. (2006). Forest Mensuration: a handbook for practitioners. Forestry Commission, Edinburgh. i–vi + 1–330pp.
Single-stand model run	A model run where only a single forest type is listed in the spplist file. A single stand run enables more details to be viewed at the per stand scale, such as species and management information.	

Name	Definition	Source
Stand	Defined in CARBINE as an area of trees with a homogenous forest type, that is, with the same combination of tree species, yield class and management prescription applied.	
Stem	The woody material forming the above-ground main growing shoot of a tree. By convention, in UK forest yield models, the stem is taken to include all commercially utilisable woody volume above ground with a diameter greater than 7 cm overbark. This may mean that significant 'straight' branches (i.e., more than 3 m in length and greater than 7 cm in top diameter) are included as part of the main stem volume.	Matthews, R.W., Jenkins, T.A.R., Mackie, E.D. and Dick, E.C. (2016). Forest Yield: A handbook on forest growth and yield tables for British forestry Forestry Commission, Edinburgh. i–iv + 1–92pp.

Name	Definition	Source
t	Metric tonne. Unit of mass of 1000 kilogrammes.	
Thinning	The periodic harvesting of trees in a woodland, involving the removal of some trees, generally for commercial utilisation, and the retention of others for future production or long-term retention.	Matthews, R.W., Jenkins, T.A.R., Mackie, E.D. and Dick, E.C. (2016). Forest Yield: A handbook on forest growth and yield tables for British forestry Forestry Commission, Edinburgh. i–iv + 1–92pp.
Top height	Top height is the mean height, in metres, of the 100 trees of largest dbh per hectare.	Matthews, R.W., Jenkins, T.A.R., Mackie, E.D. and Dick, E.C. (2016). Forest Yield: A handbook on forest growth and yield tables for British forestry Forestry Commission, Edinburgh. i–iv + 1–92pp.
Transition (management)	A change in management, species or yield class for a stand, not necessarily associated with a new rotation.	
Transition (utilisation)	Change in utilisation of wood products.	
WP	Wood products.	

Name	Definition	Source
Yield class	An index used in Britain of the potential productivity of even-aged stands of trees. It is based on the maximum mean annual increment of cumulative timber volume achieved by a given tree species growing on a given site and managed according to a standard management prescription. It is measured in cubic metres per hectare per year (m^3 ha^{-1} yr^{-1}).	Matthews, R.W., Jenkins, T.A.R., Mackie, E.D. and Dick, E.C. (2016). Forest Yield: A handbook on forest growth and yield tables for British forestry Forestry Commission, Edinburgh. i–iv + 1–92pp.
Yield table	A table giving estimates including volume, dbh and height for standing trees, mortality and thinnings. A yield table therefore shows how a stand of trees develops over time under specified conditions (species, yield class, initial spacing, and management).	Matthews, R.W., Jenkins, T.A.R., Mackie, E.D. and Dick, E.C. (2016). Forest Yield: A handbook on forest growth and yield tables for British forestry Forestry Commission, Edinburgh. i–iv + 1–92pp.

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