# Forest Carbon Assessment

Hills and Fleurieu Landscape Board

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FLINTpro

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## Disclaimer



## Confidentiality Notice

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# List of Acronyms

| | |
|---|---|
| AGB | Aboveground Biomass |
| BGB | Belowground Biomass |
| C | Carbon |
| $CO_2$ | Carbon Dioxide |
| DCCEEW | Department of Climate Change, Energy, the Environment and Water |
| DOM | Dead Organic Matter |
| FLINT | Full Lands Integration Tool |
| FPI | Forest Productivity Index |
| FullCAM | Full Carbon Accounting Model |
| GHG | Greenhouse Gas |
| HWP | Harvested Wood Products |
| NIR | National Inventory Report |
| MVG | Major Vegetation Groups |
| NGGI | National Greenhouse Gas Inventory |
| NVIS | National Vegetation Information System |
| TYF | Tree Yield Formula |

# Executive Summary

The Hills and Fleurieu Landscape Board manages approximately 670,000 hectares (ha) of land across South Australia, from Adelaide Hills to Fleurieu Peninsula. FLINTpro (formally The Mullion Group) was engaged by Hills and Fleurieu Landscape Board to model a forest carbon baseline assessment through time across the current forested land using the FLINTpro system. Only areas identified as forest were modelled, with a spatial land-use filter used to omit non-forest areas. A baseline period from 2000-2022 was established, following the requirements for a Tier 3 assessment, utlising models and inventory measurement systems tailored for national circumstances and driven by high-resolution activity data.

The results of the simulation indicate that forest carbon stocks in aboveground biomass (AGB), belowground biomass (BGB), and dead organic matter (DOM), maintained a steady rate of carbon in the pools, reducing slightly in the last seven years of the assessment period. Spatial results for forest carbon stocks were calculated in tonnes of Carbon per hectare and were 5,554 Kt C in 2022, which is 577 Kt C less than in 2000 (6,131 Kt C). The annual changes in carbon stocks indicates significant losses in carbon in 2021, 2019 and 2015, and a notable loss of carbon in 2007. The losses in 2015 and 2019 are largely related to fire events. Forest cover loss peaks in 2014 at 174.9 Kt C and remains relatively high until 2022.

The main drivers of forest carbon loss over the simulation period were identified as natural forest variability in nature reserves, edge effects from farmland/plantations/urban development, forest patchiness on properties, and plantation forestry operations.

This report outlines the methods, data and parameters used in the simulation and presents high level results.

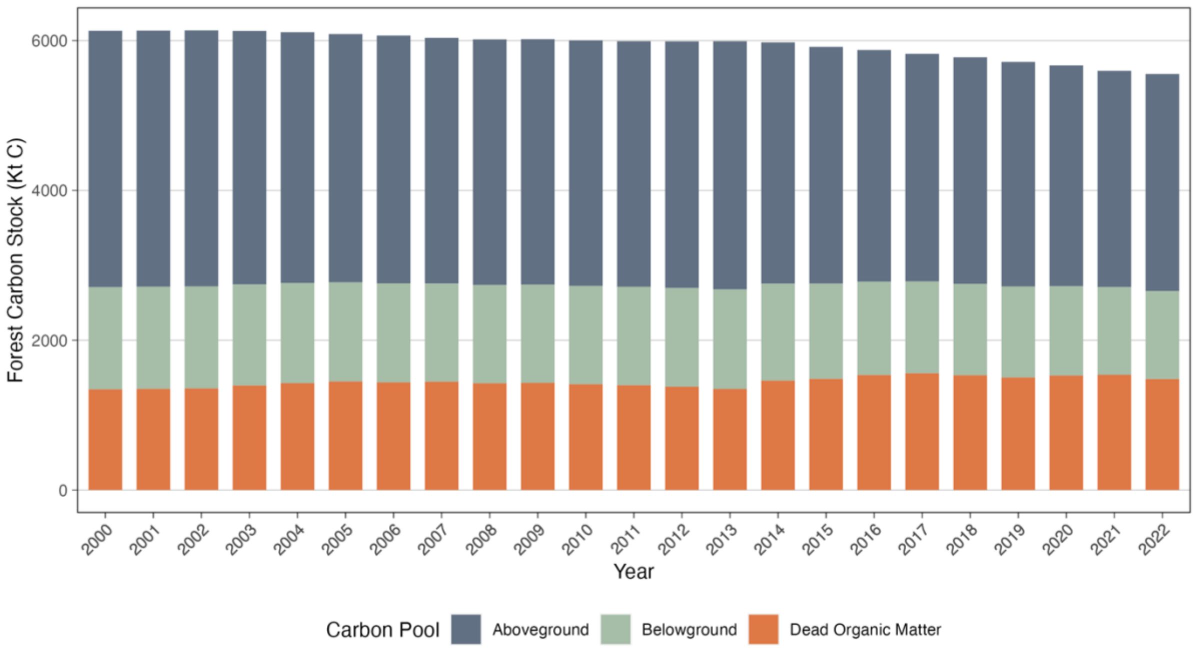


*Figure 1 - Estimates of forest carbon stock (Kt C) across Hills and Fleurieu simulation area from 2000-2022, incorporating aboveground biomass, belowground biomass, and dead organic matter.*

# 1. Introduction

This report presents the methods and results of a Tier 3 baseline carbon assessment undertaken using the FLINTpro software for the Hills and Fleurieu Region in South Australia. The assessment was undertaken across natural and plantation forestry land within the Hills and Fleurieu Landscape Board management region.

The assessment was based on a modelling system that aims to represent a series of processes and events that impact the carbon stock within forest systems. This includes:

- Sequestration (growth from photosynthesis)
- Decomposition and respiration
- Fire
- Forest cover losses (drought or human induced)
- Timber harvesting.

The underpinning models reflect those of the National Greenhouse Gas Inventory (NGGI), in particular the forest growth modelled within FullCAM (Waterworth et al. 2007). Where practicable, the simulation here aligned with the methods used in the NGGI, however a direct comparison of the results is not recommended, due to some differences in data, assumptions made and inconsistences between datasets, which are detailed in the methods.

The objective of this assessment was to, as far as practical, represent the major processes and events that occur within Hills and Fleurieu Landscape Board management region, and to quantify the associated implications on forest carbon stocks. To achieve this, a range of data sources, model components, parameters and assumptions were used within the FLINTpro system.

# 2. Methods

The results presented in this report were developed using the FLINTpro software (https://flintpro.com/). FLINTpro provides an enterprise solution for monitoring greenhouse gas emissions (GHG) and removals from the land sector. FLINTpro is built around the Full Lands Integration Tool, or FLINT. The FLINT is an open-source C++ platform that provides tools to integrate multiple data types (including remote sensing) with FLINT-compatible modules to produce spatially explicit calculations of GHG emissions and other variables.

In practical terms, FLINTpro uses temporally explicit spatial data to identify activities and events (e.g., forest loss, forest gain, fire, harvest) that impact forest carbon. The activity data is complemented with information describing the impact of the activity on the forest carbon (e.g., thinning intensities, harvest intensities, fire intensities, or forest growth rates). Carbon fluxes are quantified by applying the activity data to the respective pixel (~25x25 m) and its current carbon/biomass value. This process is undertaken for every pixel in the simulation. As FLINTpro tracks areas of land through time, carbon fluxes vary by forest type, land use and disturbance history, with younger forests having a lower carbon stock than older forests (Figure 2). FLINTpro results presented in this report include annual forest area/cover changes as well as annual carbon stocks and fluxes. These results are made available as time series of spatially explicit maps and in an aggregated tabular form for specific areas of interest. Annual GHG emissions can be generated directly from biomass-to-atmosphere fluxes or indirectly by calculating the difference in forest carbon stock from one year to another.

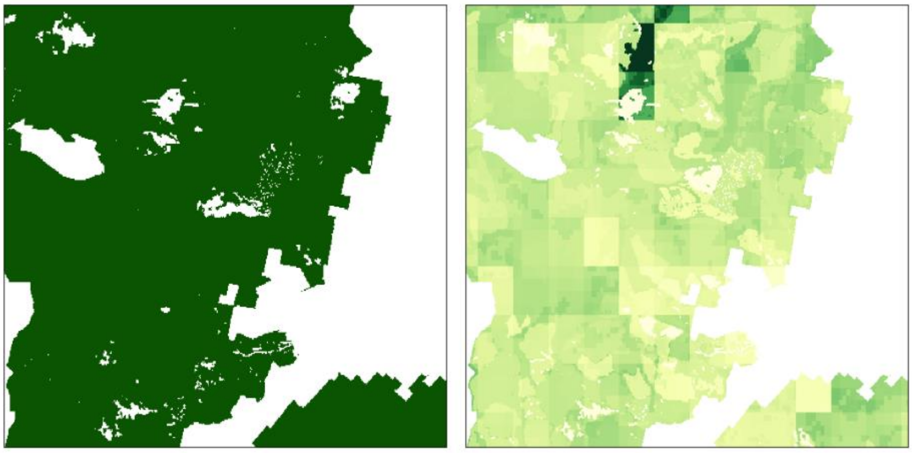

*Figure 2 - In FLINTpro, the land cover products delineating forest extent (left) are integrated with forest growth models to produce estimates of carbon stock (right) and stock changes over time.*

In this project, FLINTpro was used to model the changes in forest carbon across forests within the Hills and Fleurieu Landscape Board management region. The simulation area was provided by Hills and Fleurieu Landscape Board as a vector layer. A conceptual framework for the modelling system is shown in Figure 3. Two main drivers of change were modelled: processes, such as forest growth; and events, such as fire and forest cover loss. Processes and events are triggered by spatial data and use rules and parameters defined in aspatial (tabular) data.

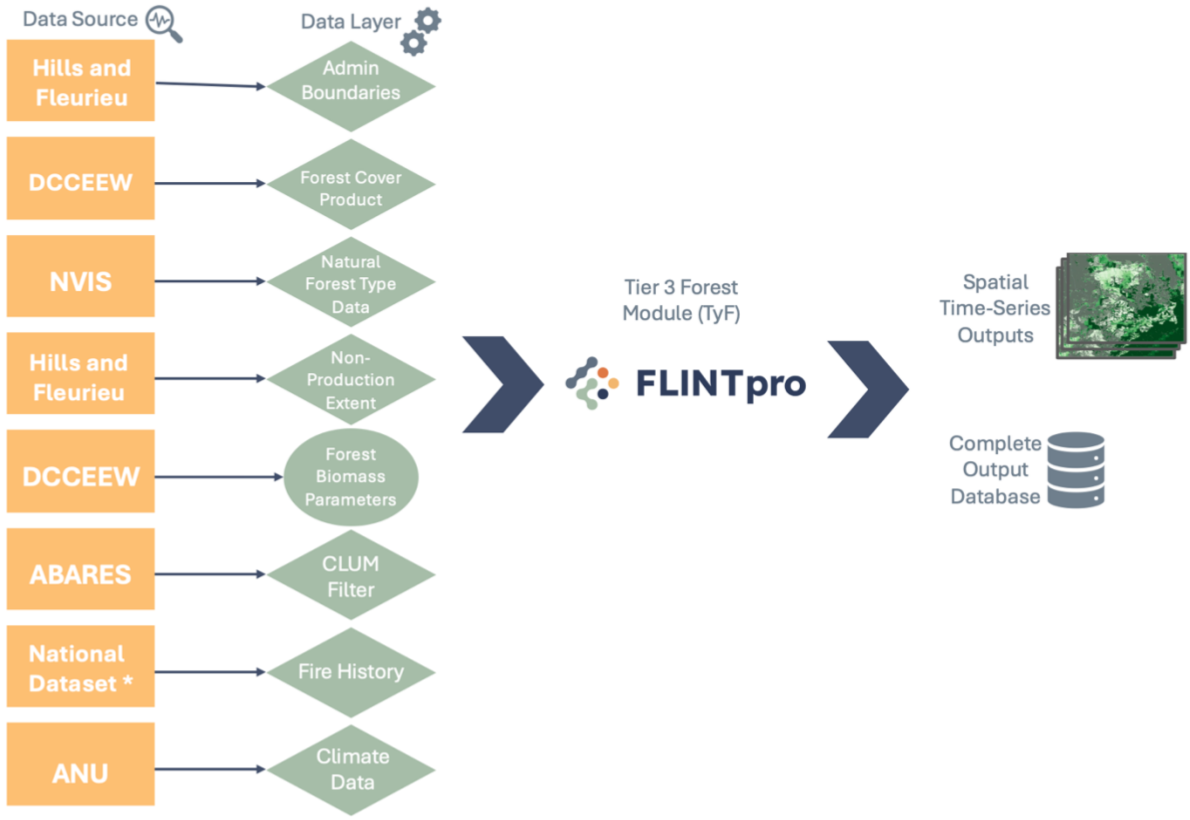


*Figure 3 - Conceptual framework for the Hills and Fleurieu carbon assessment simulation. The simulation used data principally supplied by Hills and Fleurieu Landscape Board, along with inputs from the Commonwealth Department of Climate Change, Energy, the Environment and Water (DCCEEW), Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), and the Australian National University (ANU). * National Fire data comprised from Ryu and Charalambou (2023); DCCEEW (2022); SavBAT (2018).*

## 2.1. Data

The data used in the simulation can be divided into spatial time-series data, spatial static data and aspatial data. Spatial input data (required for the model to run) are shown in Table 1 and spatial filters in Table 2. Spatial filters are used to aggregate results for different land units (e.g., land-use categories).

The aspatial data is used by the system to define forest vegetation types and event types in more detail. This data is used to allocate the biomass stored in a forest to the individual forest components (i.e., proportions of roots, stems, branches, leaves) and to define the carbon stored in the biomass of each of these components (carbon fractions). Additional data defines how much biomass transitions each year from the living biomass to dead organic matter (DOM) due to natural processes (turnover rate), how fast the DOM decays (breakdown fraction), and which proportion of the carbon contained in the DOM cycles through the soil before it is released into the atmosphere (atmospheric fraction). Aspatial data linked to events is used to describe the fraction of the biomass that is affected by a specific event and to define the related fluxes (e.g., which fraction of the biomass is moved to DOM, which fraction is moved to the atmosphere and if applicable which fraction is converted to harvested wood products (HWP). Breakdown fractions for harvested wood products are also defined in aspatial data.

In this project, the parameters and assumptions were sourced from methods used in the National Greenhouse Gas Inventory.[1]

*Table 1. Spatial Input Data.*

| Type | Data | Source | Resolution | Description |
|---|---|---|---|---|
| **Static** | **Simulation Area** | Hills and Fleurieu Landscape Board | Vector | Polygon dataset of the Hills and Fleurieu Landscape Board Management boundary in South Australia. |
| **Time-series** | **Forest Cover** | DCCEEW | 0.00025 degrees* (~25 m pixels) | National Forest and Sparse Woody Vegetation Data (Version 7.0 - 2022 Release). A woody vegetation extent product discriminating between forest, sparse woody, and non-woody land cover across; based on Landsat satellite imagery; time series from 1989 to 2022 with some gaps; forest = woody vegetation with ≥ 20 % canopy cover, potentially reaching a height of 2 metres and a minimum area of 0.2 hectares; sparse woody = woody vegetation with a canopy cover between 5-19%; In this study, sparse woody was treated as non-forest. The year 1988 was excluded from the analysis due to issues related to a change in imagery resolutions. |
| **Static** | **Major Vegetation Groups (MVG)** | DCCEEW | ~100m | Australia - Present Major Vegetation Groups - NVIS Version 6.0. This raster dataset provides summary information on Australia's present (extant) native vegetation, which has been classified into Major Vegetation Subgroups. This is based on data from each of the states and territories and provides an estimate of the current vegetation type. |
| **Static** | **Maximum AGB** | DCCEEW | (~1 km grid) | Site potential is depicted by the Maximum Above Ground Biomass (also known as M) spatial layer within the Full Carbon Accounting Model (FullCAM). |

[1] https://www.dcceew.gov.au/climate-change/publications/national-inventory-report-2021

| Type | Data | Source | Resolution | Description |
|---|---|---|---|---|
| **Static** | **Forest Productivity Index (avg)** | DCCEEW | (~1 km grid) | The Long-Term Average Forest Productivity Index (FPIavg) spatial layer within FullCAM represents the sum of key site-factors driving growth toward M (e.g., soil type, fertility, and climate). |
| **Time-series** | **Annual Forest Productivity Index** | DCCEEW | (~1 km grid) | Forest Productivity Index (Time Series). Annual product from 1970-2020. Used in the tree yield formula. |
| **Time-series** | **Temperature and Rainfall** | ANU | 0.01 degrees | Monthly average temperature and rainfall to determine decomposition rates. |
| **Time-series** | **Fire Data History** | DCCEEW | 0.00025 degrees | National dataset comprised from Ryu and Charalambou (2023); NAFI (2023); DCCEEW (2022); SavBAT (2018). Combines wildfires and prescribed fires into a 'default fire' variable. |
| **Static** | **NPI Region** | ABARES (2016) | Vector | National Plantation Inventory Regions of Australia. |

* The coordinate reference system (CRS) EPSG:4326 - WGS84 was used for all spatial data. Data was transformed to this CRS where required.

*Table 2. Spatial Filter Data.*

| Type | Data | Source | Filter Name | Description |
|---|---|---|---|---|
| **Static** | **Major Vegetation Groups** | DCCEEW | MVG 6.0 Filter | Australia - Present Major Vegetation Groups - NVIS Version 6.0. |
| **Static** | **Project Area Filter** | ABARES (2021) | CLUM Filter | Polygon dataset clipped to the simulation area, comprising of national compilation of catchment scale land use data for Australia (CLUM) dataset. |

### 2.1.1. Forest cover and type

Forest parameters for natural forest were derived from the National Inventory Report 2021[2]. Information includes:

- Carbon Fractions and Turnover Rates (Table 7 in the Appendix)
- Resistant fractions and forest component allocations (Table 8 in the Appendix)
- DOM Breakdown fractions (Table 9 in the Appendix)
- Breakdown fractions for harvested wood products (Table 10 in the Appendix)

The locations of the different forest vegetation types were defined by the Major Vegetation Groups (MVG) layer. Forest cover is based on the National Forest and Sparse Woody Vegetation data, which is a time-series from 1988 to 2022 defining three land cover classes: forest, sparse woody vegetation and non-forest. In Australia, forest is defined as areas containing trees with 20% canopy cover and greater than 2m in height. Sparse woody contains trees with 5-20% canopy cover. Note that 1988 data was not used here, due to some inconsistencies identified with this year.

[2] https://www.dcceew.gov.au/climate-change/publications/national-inventory-report-2021

## 2.2. FLINTpro simulation

Where possible, general consistency with the methods, assumptions, and data used for Australia's National Greenhouse Gas Inventory (NGGI) was maintained. However, this study is not completely consistent with the NGGI, and a direct comparison of the results is not recommended. For example, non-$CO_2$ emissions from fire are not included in this report. In addition, the NGGI includes soil carbon and non-forest areas, whereas this study does not. Soil carbon was not modelled here because detailed land management information is required to represent soil carbon with confidence.

As mentioned previously, there are two main drivers of changes in carbon: processes and events. Processes include sequestration (growth), turnover and decomposition. Events can be natural events such as fire (combustion) and human interventions, such as cutting down trees within a forest for timber (harvesting) or removing forests from areas of land (clearing). Processes tend to occur continuously over time, whereas events are often episodic, and thus occur relatively discretely over limited timeframes. From the initial aboveground biomass calculations, a total of 39 carbon pools are modelled, with carbon movements resulting from processes (growth, turnover, and decomposition) and events (harvesting, clearing and fire). The simulation was run from 1935 to 2022 to allow a 'spin up' period. This spin up period serves the purpose of allowing the dead organic matter pool to develop and reach an approximate equilibrium state by the time the period of interest begins in 2000.

### 2.2.1. Processes

Forest growth for natural forests was simulated using the Tree Yield Formula (TYF; Waterworth et al. 2007) which is described in more detail in the Appendix (0). The TYF uses the site potential as depicted by the Maximum Above Ground Biomass (also known as M) as an input parameter. The M layer used is the same as in the National Inventory (Roxburgh et al. 2019). The TYF also uses the Forest Productivity Index (FPI) to modify growth rates, in this analysis a long term FPI was applied, such that annual climatic variations in forest growth were not included.

### 2.2.2. Events

Events are operations that occur intermittently (rather than every time step in a simulation) resulting in the movement of carbon from one pool to another. In the Hills and Fleurieu simulation, the main events that were modelled included forest cover loss, forest cover gain and fire.

#### Forest Loss

If a pixel changes from forest in one year to non-forest the next year, a forest loss event is triggered between the two observations. This activity results in the flux of carbon from the living biomass pools (above ground and below ground) to dead organic matter; carbon that decomposes over time.

Carbon fluxes related to the soil organic carbon are not included in this assessment, and since soil is not included, all decomposed dead organic matter is directly moved as emissions to the atmosphere.

### Forest gain

When a pixel changes from non-forest to forest, a growth function is initiated, starting the accumulation of carbon on that pixel. This results in fluxes of carbon from the atmosphere to the pixel's biomass pools over time. The growth of below ground biomass is simulated as a fraction of above ground biomass, using vegetation type-specific parameters. Dead organic matter accumulates from dying branches, leaves and roots which decompose over time.

### Fire

Fire is an important event type in the Australian context and is integral to much of Australia's forest ecology. Annual forest fire maps determine the type and timing of forest fire activity. Forest fire activity only affects a portion of the forest biomass. This portion is partially emitted directly into the atmosphere and partially transferred to the dead organic matter pool. It is differentiated between prescribed burning and wildfire. The specific event parameters are derived from the National Inventory report 2019 (DISER 2021). Methane ($CH_4$) and nitrous oxide ($N_2O$) emissions that are released along with carbon dioxide ($CO_2$) during a forest fire event are not included in the results. Any limitations in the fire extent data will be carried through to the results. It is expected that the older data will be of lower spatial accuracy than modern data. An assessment of the completeness and accuracy of these data was not completed as part of this project.
Beyond timing and extent, the modelling system incorporates patchiness and proportion of biomass consumed. Within the boundaries of a fire affected area, not all the area is burnt, rather there are often patches of unburnt areas. This is referred to as 'patchiness'. Similarly, when an area is physically burnt, not all the available biomass is consumed. To account for both concepts, an estimate of patchiness and proportion of biomass consumed was included in the fire model.
Fire type Patchiness (P) in Southern Australian forests and woodlands was 0.650 for prescribed fires and 0.800 for wildfires, as used in the National Inventory. Where a fire is applied, all pixels within the fire boundary are affected by the fire event. The patchiness factor is then applied to the resulting carbon changes to represent incomplete coverage of the burning. Depending on the fire type, different fractions of biomass were moved from the carbon pools to either atmosphere or dead organic matter (Table 3). Note that in this simulation, the root mass of trees is not affected by fires.

*Table 3 - Fraction of carbon in living tree pools that was moved to the atmosphere or dead organic matter in response to prescribed fire or wildfire events, as applied between 1950 and 2017.*

| Fire Type | | Fraction of Named Pool to Atmosphere | | | | Fraction of Named Pool to Dead Organic Matter | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Patchiness | Stem | Branch | Bark | Leaf | Stem | Branch | Bark | Leaf |
| Prescribed Fire | 0.65 | 4.5% | 4.5% | 4.5% | 2.5% | 0.5% | 0.5% | 0.5% | 0.5% |
| Wildfire | 0.8 | 9.0% | 9.0% | 9.0% | 5.0% | 1.0% | 1.0% | 1.0% | 5.0% |

## 2.2.3. Output filter

The national compilation of catchment scale land use data for Australia (CLUM) dataset (ABARES, 2021) was used as an output filter in FLINTpro, to be applied to the results. The CLUM layer comprises of land tenure and other types of land use information, with various levels of detail descriptors in the attribute table of the spatial dataset. For the H&F baseline analysis, it was used to filter out areas that are not forest change, in particular vineyards and orchards that are mistakenly processed as forested areas in the National Forest and Sparse Woody data. Through Google satellite

(Google Earth Pro) visual analysis of the FLINTpro spatial results overlayed with the CLUM spatial layer, specific categories of the CLUM filter could be selected to then be excluded in the results analysis (Table 4). A visualisation of the CLUM layer being used to filter out non-forested areas of the simulation area are shown in Figure 4.

*Table 4 – Relevant output filter specifications for the national compilation of catchment scale land use data for Australia (CLUM) dataset, used to filter out non-forested areas in the Hills and Fleurieu simulation area.*

| CLUM layer attribute category | FLINTpro CLUM filter attribute titles excluded as non-forest areas in the results |
|---|---|
| 3 Production from dryland agriculture and plantations | '3.4.1 Tree fruits' |
| 4 Production from irrigated agriculture and plantations | '4.4.1 Irrigated tree fruits',<br>'4.4.2 Irrigated olives',<br>'4.4.3 Irrigated tree nuts',<br>'4.4.4 Irrigated vine fruits',<br>'4.4.5 Irrigated shrub berries and fruits',<br>'4.4.8 Irrigated citrus',<br>'4.4.9 Irrigated grapes',<br>'4.5.1 Irrigated seasonal fruits',<br>'4.5.3 Irrigated seasonal vegetables and herbs', |
| 6 Water | '6.3.0 River',<br>'6.2.0 Reservoir/dam',<br>'6.2.1 Reservoir',<br>'6.2.2 Water storage - intensive use/farm dams',<br>'6.4.3 Stormwater', '6.4.0 Channel/aqueduct',<br>'6.4.1 Supply channel/aqueduct',<br>'6.4.2 Drainage channel/aqueduct',<br>'6.3.1 River - conservation', '6.3.2 River - production',<br>'6.1.1 Lake - conservation', '6.1.2 Lake - production',<br>'6.1.3 Lake - intensive use', '6.1.0 Lake',<br>'6.6.0 Estuary/coastal waters',<br>'6.6.1 Estuary/coastal waters - conservation',<br>'6.5.1 Marsh/wetland - conservation',<br>'6.5.2 Marsh/wetland - production',<br>'6.5.0 Marsh/wetland' |

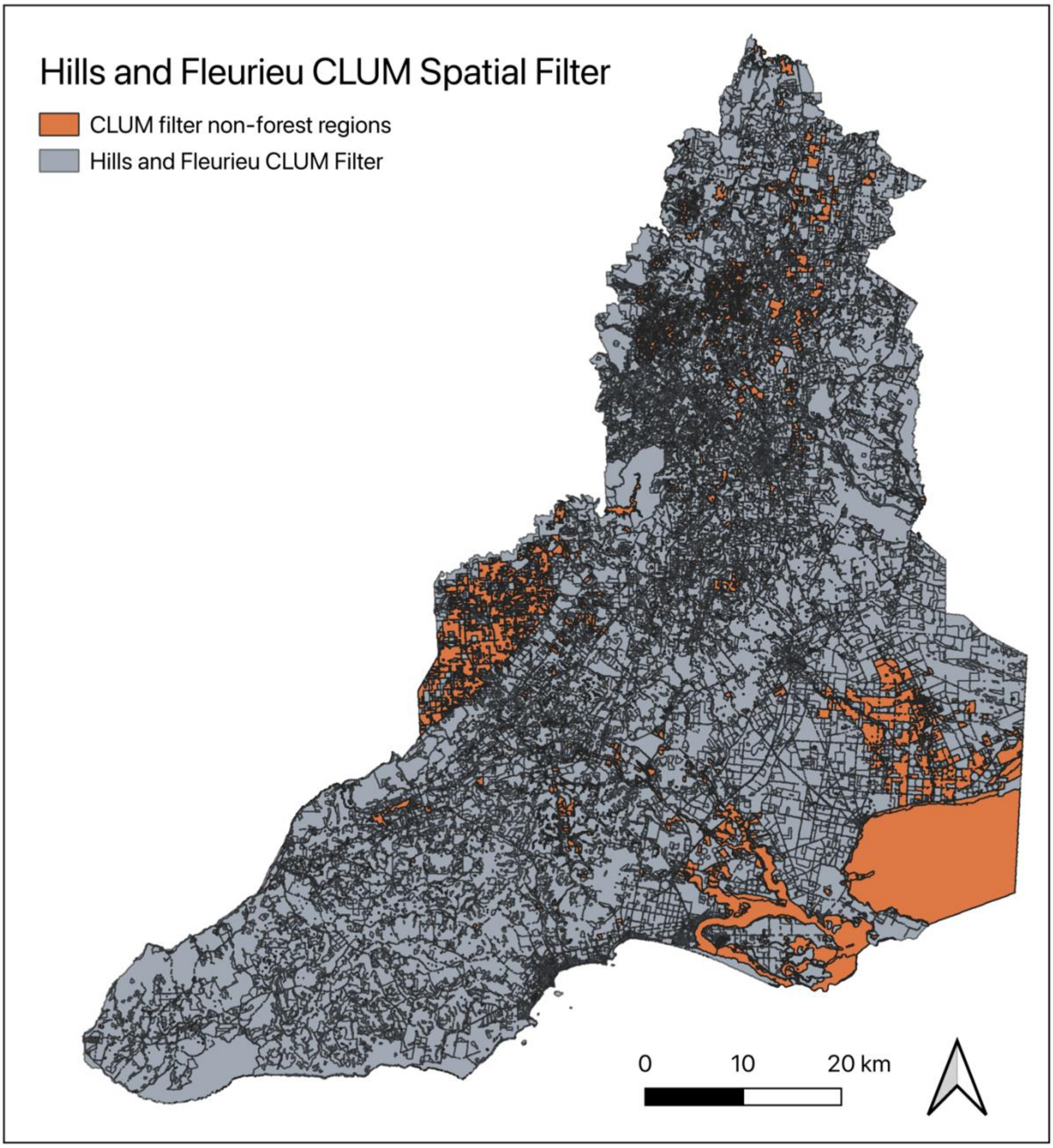


*Figure 4 – National compilation of catchment scale land use data for Australia (CLUM) dataset used as an output filter (blue), clipped to the Hills and Fleurieu simulation boundary in South Australia. Orange regions indicate the attributes outlined in Table 4 as the non-forest land use areas to be masked out of the results analysis.*

### 2.2.4. Fluxes

FLINTpro tracks carbon fluxes between different pools. In this simulation, it was configured to track carbon between the following pools: aboveground, atmosphere, belowground, and dead organic matter. The system also assigns a flux type to each movement of carbon. The flux types used here included:

- Fire
- Forest Cover Loss
- Turnover
- Net primary productivity (NPP) or forest growth
- Decomposition

This set-up enables specific fluxes and their associated causes to be analysed in detail, in particular allowing emissions due to fire to be separately identified.

# 3. Outputs and results

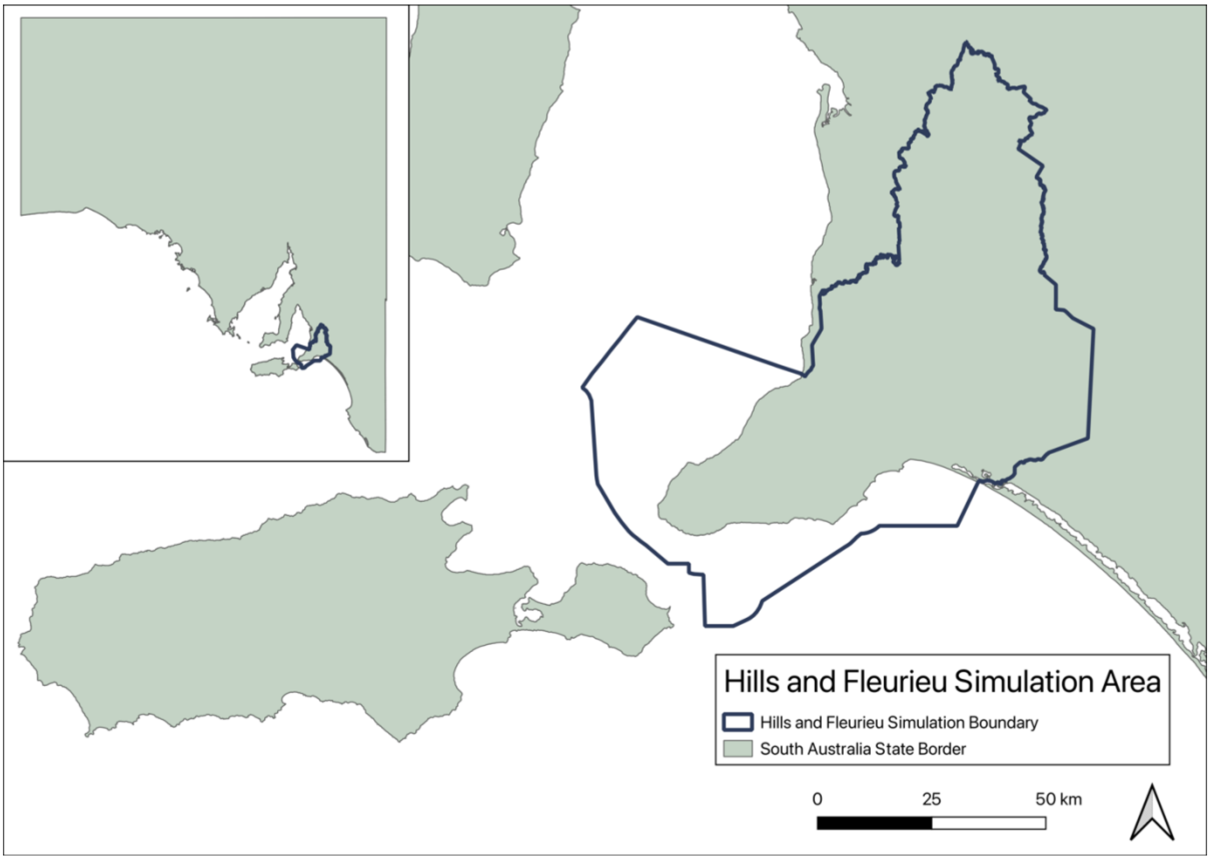


*Figure 5 – Hills and Fleurieu simulation boundary for the carbon baseline assessment, located in South Australia. Note that the boundary includes the marine boundary which is reduced in the following spatial mapped results to include the terrestrial boundary only.*

As described above, changes in forest carbon stock within the Hills and Fleurieu study area (Figure 5) are driven by processes and events triggered by spatially and temporally explicit datasets. In the forest land, events are only triggered by forest cover losses and gains in the national forest cover data as well as fire events from the national fire history dataset.
In the following results, only carbon in the aboveground, belowground, and dead organic matter pools are shown. Note that soil carbon is not included in this analysis.

Forest carbon stocks (aboveground biomass, belowground biomass, and dead organic matter) across the Hills and Fleurieu Landscape Board Management for the period 2000-2022 are shown in Figure 6. Forest carbon stocks (AGB, BGB, DOM) in 2022 were 5,554 Kt C, which is 577 Kt C less than in 2000 (6,131 Kt C). The percentage change of total forest carbon stock from minimum (5,554 Kt C in 2022) to maximum (6,137 Kt C in 2002) was 9.49 %, and the maximum change in a single year was -72.3 Kt C from 2020 (5,668 Kt C) to 2021 (5,596 Kt C). Section 3.1 details the key drivers of the change in carbon stocks.

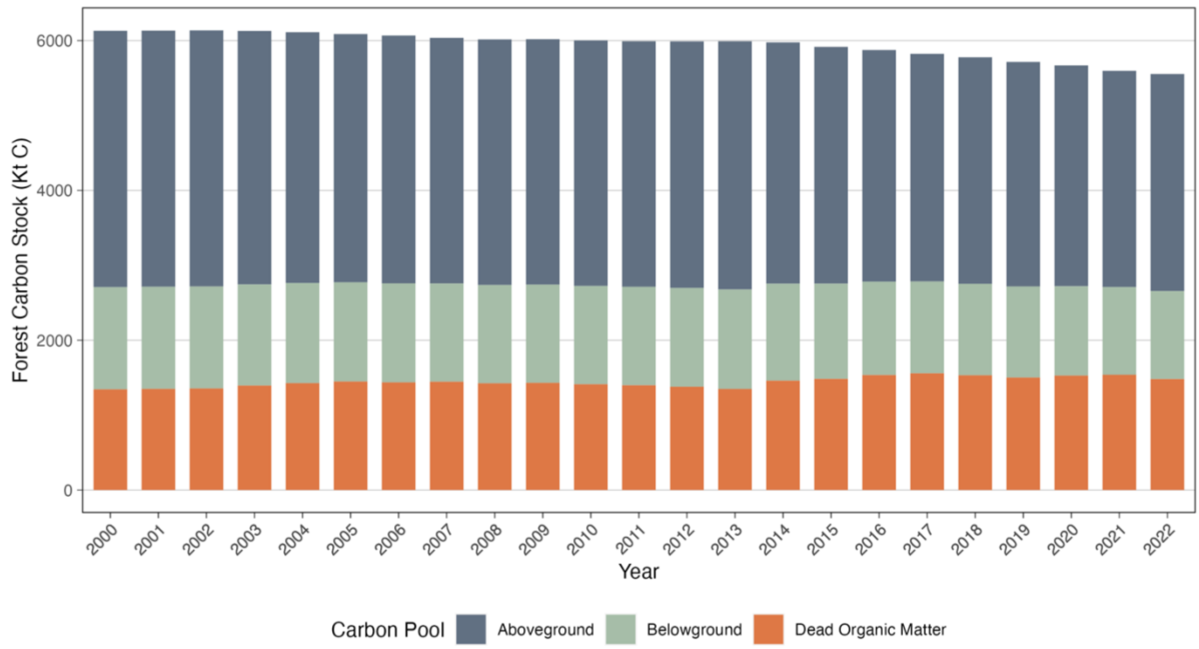


*Figure 6 - Estimates of forest carbon stock (Kt C) across Hills and Fleurieu simulation area from 2000-2022, incorporating aboveground biomass, belowground biomass, and dead organic matter and excluding relevant non-forest areas in the CLUM filter.*

The annual changes in carbon stocks are shown in Figure 7. This indicates that there was a significant loss of carbon in 2021, 2019 and 2015, and a notable loss of carbon in 2007. The losses in 2015 and 2019 are largely related to fire events, that both impacted the northern region of the simulation area. A map showing the change in carbon stocks between 2000 and 2022 is shown in Figure 9.

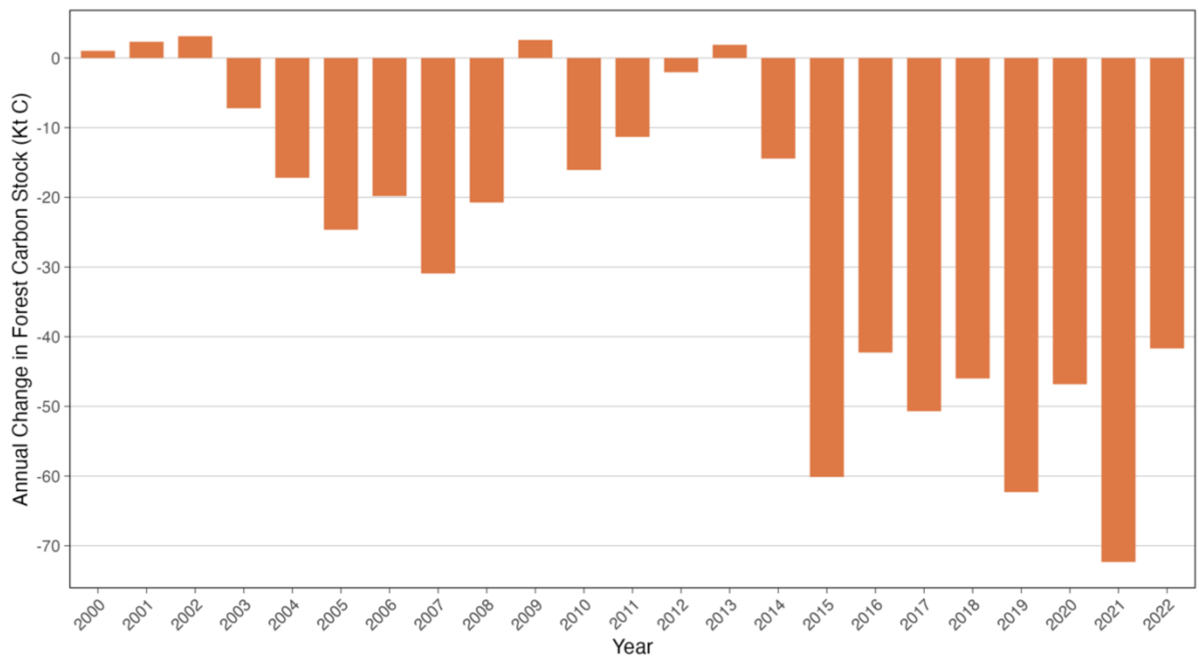


*Figure 7 - Net annual change in forest carbon stock across Hills and Fleurieu simulation area from 2000-2022, including AGB, BGB, and DOM. Excluding non-forest areas in the CLUM filter. Negative numbers indicate a net loss in forest carbon, while positive numbers represent a net gain in forest carbon.*

Carbon fluxes associated with forest cover loss and fire events are shown in Figure 8. Note that these are not emissions, but movements of carbon from one pool to another. The data indicates notable fluxes due to fire in 2015 (38.6 Kt C) and 2019 (43.1 Kt C). Forest cover loss peaks in 2014 at 174.9 Kt C and remains relatively high until 2022. Decomposition and NPP carbon pools remain steady, with NPP reducing steadily from a maximum in 2013 (459.9 Kt ) to 2022 and decomposition increasing slightly in that same period with a maximum of 479.7 Kt C in 2017.

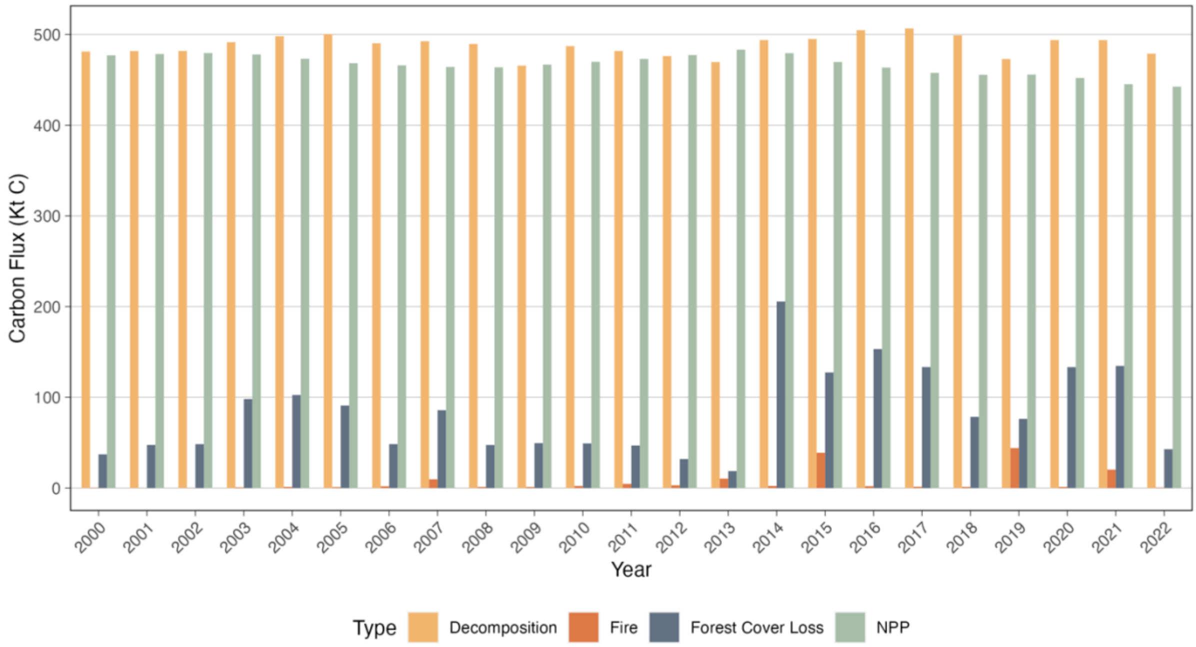


*Figure 8 - Carbon fluxes due to decomposition, fire, forest cover loss and NPP, across the Hills and Fleurieu simulation area between 2000 and 2022. Note that fluxes are not emissions, they represent movements from one pool to another.*

## 3.1. Carbon Stock Drivers

The forest carbon difference from 2000 to 2022 (Figure 9) shows the areas of significant carbon loss (red). Analysis across the time-series, relating to unique forest carbon stock changes, was done to better understand the regional causes, whether natural or human-induced. Regions with high carbon loss were visually analysed using Google Earth Pro, to identify the forest appearance throughout the time-series, by google satellite records. Due to this, images were not available in the early-2000s, and the earliest useable quality images varied in each case.

Four major causes of forest carbon variability have been identified in the Hills and Fleurieu simulation area over the assessment period. These were,

i. Natural forest cover variability. This was evident in the northern regions of the simulation area, particularly the Kersbrook forest reserve and the Mount Gawler Forest Reserve.
ii. Edges of urban land and agriculture pastures/farm boundaries that are picked up as forest land. The CLUM filter was used to remove most of these impacted areas, however due to the adjustment of the native vegetation border between 2000 to 2022, and/or the impacts of forest-clearing for plantation establishment.
iii. Forest loss in patches on farmland/properties. These areas are likely to undergo change due to land management/development and reduced natural forest structure.

iv. Plantation forestry variability, particularly the softwood plantations in the southern (near Delamere, SA) and central (southwest of Meadows, SA) regions of the simulation area. These areas undergo high levels of variability due to plantation establishment and harvesting events.

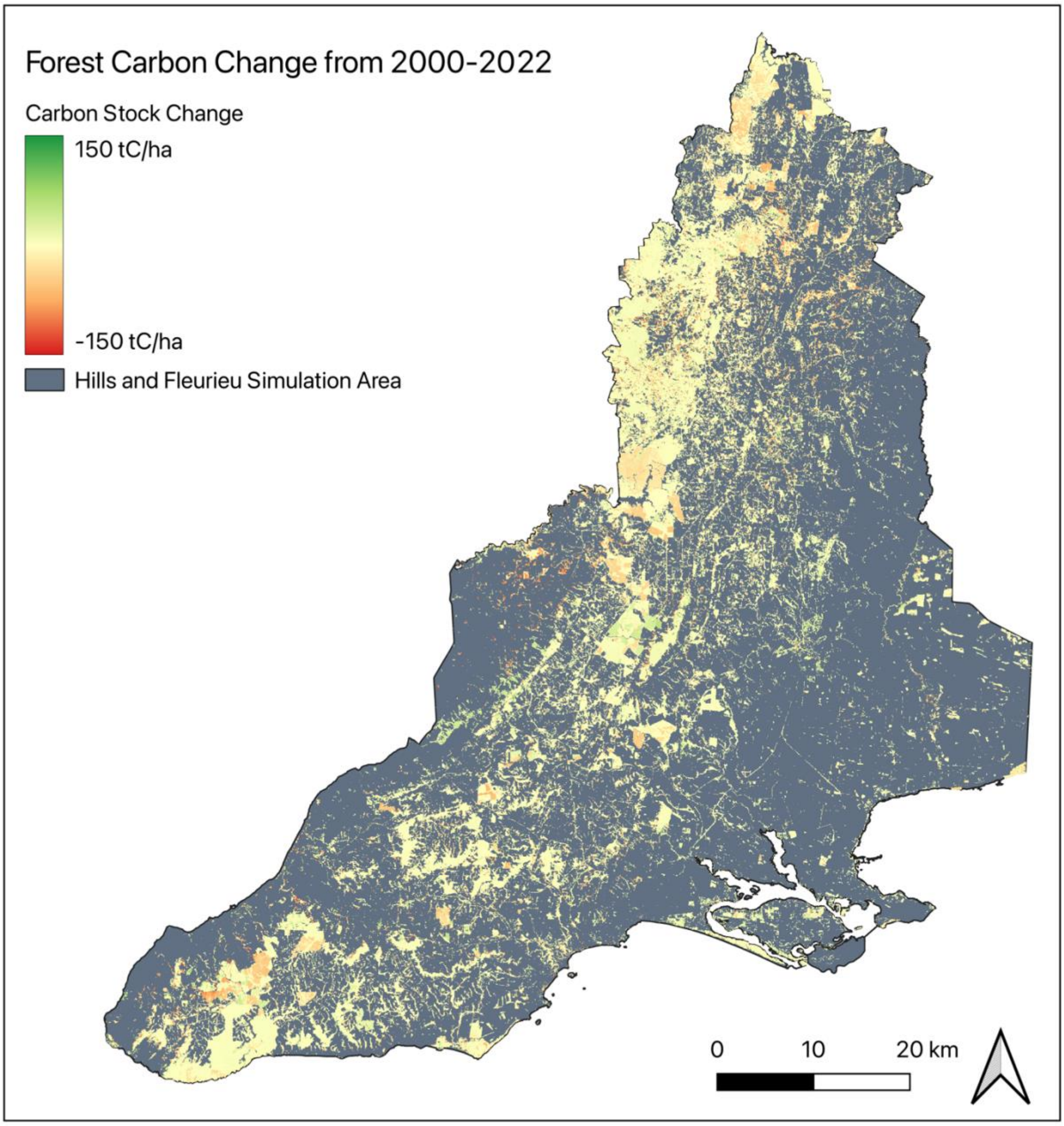


*Figure 9 – Forest carbon stock (AGB, BGB, DOM) change between 2000-2022, negative values (red) indicate carbon stock loss and positive values (green) indicate carbon stock gains. The CLUM spatial filter has been applied, masking out areas that are classified as non-forest land-uses.*

# 4. Limitations and areas for improvements

The FLINTpro system models changes in carbon through time based on various sources of input data which drive processes and events. The quality of the outputs is therefore inherently linked to the quality of the inputs. For the Hills and Fleurieu region, improved data inputs, especially with respect to forest loss and gain events, could provide better outputs, in particular the underpinning forest biomass potential layer.

Assessing the accuracy of the location and timing of fire events specifically for the Hills and Fleurieu region may improve the estimation of the impact of fire events. Generally speaking, historical fire records are less reliable than more recent. More recently, fire agencies in Australia and across the world have started to map fire severity using broad classes (e.g., extreme, high, moderate, low). Incorporating specific carbon flux parameters for fire severity classes is recommended where data supports this.

One of the principal factors dictating overall forest carbon levels is the maximum biomass (M) layer (Roxburgh et al. 2019), used by both the national inventory and FLINTpro. This layer is what all forest grows towards. It has been identified that in several areas of Australia, there are extremely high biomass values in some areas, while in nearby areas values are comparatively low (e.g., 2000 next to 600). A more accurate M layer would naturally lead to more accurate estimates carbon stock numbers, however, it is noted that these extremes were not observed in the Hills and Fleurieu region.

# 5. Appendix

## 5.1. Background into the Carbon Cycle

Carbon occurs within the earth systems in various compositions, including solid and gaseous states. Carbon moves between these states as well as between different reservoirs (or pools) in the oceans, terrestrial biosphere, and atmosphere via a range of exchanges sometimes referred to as ‘pathways’. The movement of carbon through these pathways to different carbon pools collectively comprises the carbon cycle. A simplified representation of the forest components of the carbon cycle is provided in Figure 10.

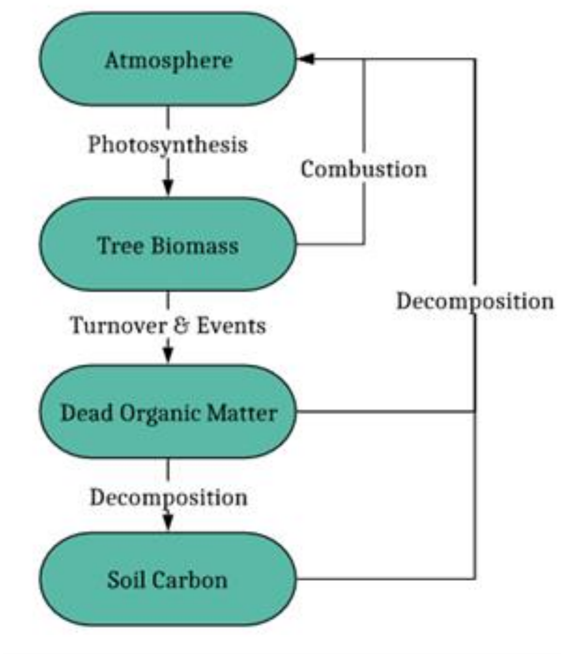


*Figure 10 – Simplified example of the natural carbon cycle, with the cyclical movement of carbon from the atmosphere into three terrestrial carbon pools, and back to the atmosphere.*

There are two distinct causes for the movement of carbon along the pathways: processes and events. Processes include sequestration (growth), turnover and decomposition. Events can be natural events such as fire (combustion) and human interventions, such as cutting down trees within a forest for timber (harvesting) or removing forests from areas of land (clearing). Processes tend to occur continuously over time, whereas events are often episodic, and thus occur relatively discretely over limited timeframes.

### Sequestration (plant growth)

Sequestration by plant growth is the process by which plants remove gaseous $CO_2$ from the atmosphere and store it in solid form as plant biomass. Approximately 50% of plant biomass (dry weight) is composed of carbon (C). In simple terms, plants, both aquatic and terrestrial, will absorb water ($H_2O$) and $CO_2$, and through photosynthesis, transform these elements into carbohydrates and oxygen. These carbohydrates form the basis of all plant material, including stem and branch wood, bark, leaves, and roots.

### Decomposition and Respiration

As plants and forests grow, various tissues die, such as branches, leaves, roots and even whole trees. This transfers these forest components from the living pool to the dead organic matter pools. Where individual tree components die and are then regrown, such as branches, leaves, and roots, this is referred to as 'turnover'. Once in the dead organic matter pool, decomposition normally commences. Decomposition is the breakdown of plant material into simpler elements, including carbon dioxide, which is released back to the atmosphere.

Decomposition is rarely complete, and the process generally results in carbon moving from being classified as dead organic matter into soil organic carbon (SOC). SOC will continue to breakdown, although where the inputs are greater than the decomposition rates, there can be an accumulation of carbon in soil. Soil carbon is therefore a balance between inputs from dead organic matter and dead root material and outputs due to decomposition, respiration from decomposers and oxidation.

### Fire (Combustion)

Fire is a critical component of Australia's forests, and in many systems required for the health of the forest system. Fire can be either a natural or a human induced event, with two implications for the carbon cycle. One is that fire kills trees and tree components, moving carbon from living biomass to dead organic matter where it will decompose. The second is the combustion of carbon during the fire event, releasing $CO_2$ and other greenhouse gases (GHG) such as methane and nitrous oxide back to the atmosphere. Unlike decomposition, where dead organic matter is slowly lost over many years, combustion typically results in the rapid loss of dead organic matter and some of the living biomass pool.

### Other Events

Other events that impact on forest carbon are human management activities such as harvesting and clearing as well as natural events, such as die-back, insect outbreaks and windstorms. Harvesting refers to management of the area of forest for timber production and includes the removal of some or all trees from an area followed by activities to promote trees to regrow. Harvesting results in the movement of carbon from living pools to harvested wood products and dead organic matter pools. Harvesting is distinct from clearing (deforestation). Clearing involves the permanent removal of living trees from an area of land. Harvested forest areas are regenerated after a harvest event (Ximenes et al 2012). Natural events, including die-back, are where natural processes result in widespread death of trees, such as through pests and diseases. Harvesting, clearing, and natural events result in the movement of carbon stored from living biomass to the dead organic matter pools, where they will decompose, moving carbon into the soil carbon pools or return it to the atmosphere.

## 5.2. Processes

### 5.2.1. Forest Types & Growth Parameters

*Native Forests*

The forest types used in the simulation are based on the National Vegetation Information System (NVIS) Major Vegetation Groups (MVG 6.0). Growth of each type of forest reflects local climate and soil conditions and historical disturbances such as fire and human intervention. Modelling how these forests grow and respond to changing conditions is complex and requires assumptions based on the best available research and other information sources.

Given the requirement of this project to use methods consistent with the NGGI, FLINTpro was configured to model forests in a manner consistent with FullCAM. FullCAM is applied at the national scale for land sector GHG emissions accounting, and at the local scale for monitoring and reporting carbon sequestration projects under the Australian Carbon Credit Units (ACCU) Scheme, such as revegetation and the management of regrowth.

In modelling forest biomass, aboveground biomass in trees is initially estimated, after which belowground biomass, dead organic matter, harvested wood products, and soil carbon can be calculated. To estimate the aboveground biomass, FullCAM uses a hybrid of empirical and process-based modelling represented by a Tree Yield Formula (TYF; Equation 1; Waterworth et al. 2007). The process-based modelling component uses the forest growth model 3-PG (Landsberg and Waring 1997) to derive a dimensionless index (the Forest Productivity Index, or FPI) that indicates potential site productivity for any given location and year based on the Normalised Difference Vegetation Index (NDVI), soil fertility, vapour pressure deficit, soil water content, and temperature (Kesteven and Landsberg 2004).

**Equation 1**

$$\Delta AGB = M \times r \times [exp(-k/A_2) - exp(-k/A_1)] \times (FPI_t/FPI_{avg})$$

Where:

ΔAGB = Current annual increment in above-ground biomass (AGB, Megagram Dry Matter per Hectare Per Year (Mg DM per $ha^{-1}$ $year^{-1}$))

M = Maximum AGB in undisturbed native vegetation (Mg DM $ha^{-1}$)

r = value of the Type 2 multiplier to account for factors that increase growth potential at a given site (e.g. planting configuration, Snowdon 2002)

$A_1, A_2$ = age (years) in year 1 and 2, respectively, etc.

$k$ = 2 x G - 1.25, where G = tree age of maximum growth rate (years),

$FPI_t$ = Annual Forest Productivity Index over the period A1 to A2, and is the sum of site factors (soil type, fertility and climate) driving growth, regardless of the type of planting or its age (Kesteven et al. 2004); and

$FPI_{avg}$ = mean long-term average annual forest productivity index based on data, which is independent of age (Kesteven et al. 2004).

The TYF is used to simulate growth in both natural forests and plantations. For plantations, $r$ is also influenced by M (DISER 2022) where:

$r = \exp(ar) \times M^{br}$, if $\text{MIN}_{r\times M} \le r \times M \le \text{MAX}_{r\times M}$ , else

$r = \text{MIN}_{r\times M} / M$, if $r \times M < \text{MIN}_{r\times M}$ , or

$r = \text{MAX}_{r\times M} / M$ , if $r \times M > \text{MAX}_{r\times M}$ .

First, $r$ ($\exp(ar) \times M^{br}$) is calculated for a location, and is multiplied by $M$ for that location, to give $r \times M$. If $r \times M$ is within the bounds ($\text{MIN}_{r\times M}$, $\text{MAX}_{r\times M}$) then $r \times M$ (as calculated above) is used in the TYF. If $r \times M$ is less than $\text{MIN}_{r\times M}$ $\text{MIN}_{r\times M} / M$ is used for $r$ . If $r \times M$ is greater than $\text{MAX}_{r\times M}$ then $\text{MAX}_{r\times M} / M$ is used for $r$.

The parameters used for plantation growth in this simulation are shown in Table 5

The values of M are provided by a CSIRO developed spatial file, representing the maximum potential biomass of an undisturbed native forest (Roxburgh et al. 2019). Whereas the value of k, as calculated from G, is set based on forest type and defined within a database. The G parameter represents the age of maximum growth and is generally constant between native forest types and varies by species and location for plantations. The lower the value of G, the faster the forest grows.

Within FullCAM, there are three key G parameters for native forests, 6.37, 10, and 12.53. These represent the calibrations for Environmental Plantings Block (6.37), Default User Defined Value (10), and Human Induced Regeneration (12.53). Within the NGGI, a G value of 12.53 is applied to all natural forests that are outside of state forests, while a G value of 6.37 is applied to natural forests in state forests (Collett pers comm. April 2021). The effect being that within the NGGI, natural forests in state forests will grow at a faster rate than the adjacent national park.
In this project, a G value of 10 was used for all native forests (i.e., not plantations).

*Plantation Forests*

No plantations were modelled for this analysis, this section is for reference with respect to potential improvements. Within FullCAM, plantation forests are modelled using the same growth function (Equation 1) as with the native forests, but with specific plantation calibrations (Roxburgh et al. 2019). The G and r parameters vary for the plantation species based on National Plantation Inventory (NPI) reporting area, and species. The plantation calibrations also vary by plantation type (hardwood or softwood) and management regime (long rotation or short rotation). Where a plantation species falls within an NPI region but does not have a specific calibration, natural forest calibrations can be applied.

*Table 5 - Parameters used in the Tree Yield Formula (TYF) to simulate the growth of plantations*

| ID | Species | MIN rxM | MAX rxM | G | ar | br |
|---|---|---|---|---|---|---|
| 201 | *Pinus radiata* | 146 | 654 | 6.311 | 3.828 | -0.617 |
| 207 | Hardwood | 104 | 448 | 6.745 | 3.23 | -0.584 |

### 5.2.2. Biomass-based Age Adjustments

The modelling system uses the age of the forest to calculate the annual growth rate, and the nature of the growth curve results in a decline in growth rates after the age of maximum growth until the maximum potential biomass for a site is achieved. When there is a thinning event, where biomass is removed from the site, it is therefore necessary to adjust the growth rates such that a 'functional age' based on biomass rather than the actual age is applied. To achieve this, a biomass-based age adjustment was configured into FLINTpro. This function back-calculates a functional age of the forest given the amount of biomass that is present. The effect being if biomass is lost from the forest through harvesting or fire, the forest will recover at a rate equivalent to a younger forest than the 'true' age of the forest (i.e., sequester carbon at a faster rate). In the absence of this functionality, modelling of mature forests that have very slow (or no growth) would not recover following the disturbance (Figure 11) which is not realistic. This age-related growth adjustment is a characteristic of FullCAM's TYF, and its use is consistent with the FullCAM guidelines for modelling plantations. FLINTpro differs from FullCAM in that when a biomass age adjustment is applied, the age advancements from treatments are removed. This is an error in FullCAM and results in a minor change in growth rates post disturbance for forests with a growth advancement in the FLINTpro implementation.

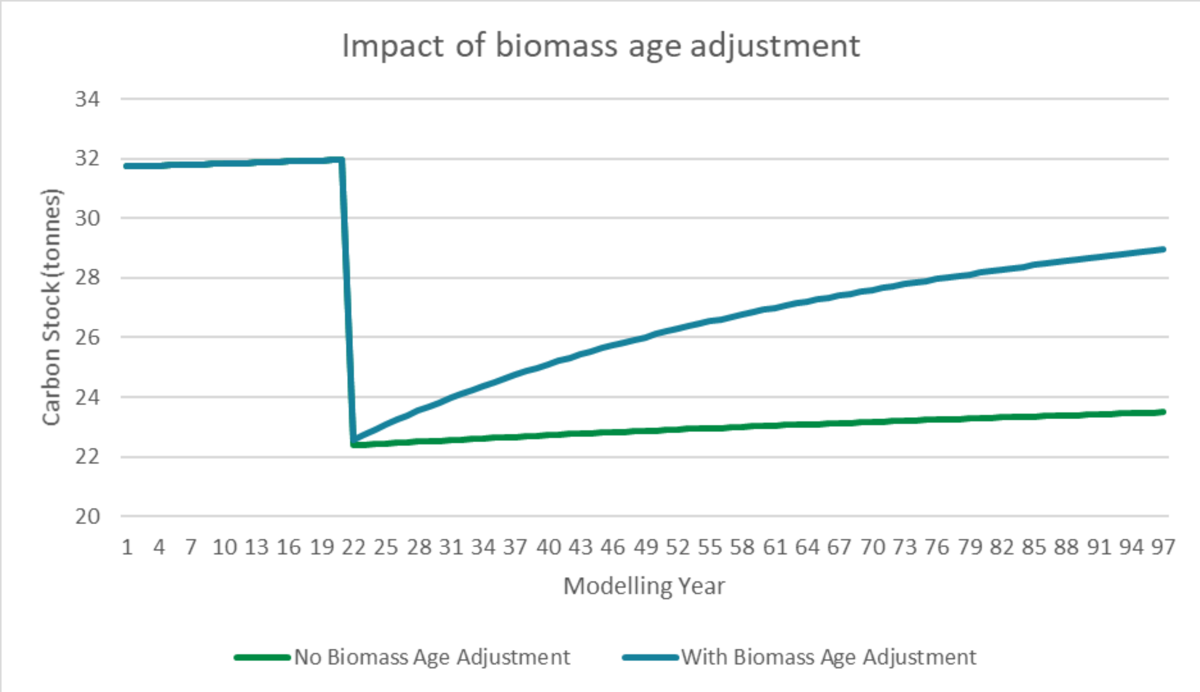


*Figure 11 – Demonstration of the impact of biomass age adjustment as modelled in FullCAM and replicated in FLINTpro. Without biomass age adjustment, following a disturbance the forest continues to accumulate carbon at the same rate as prior to the disturbance. With biomass age adjustment turned on, the forest will grow at the rate of a functionally younger forest.*

### 5.2.3. Carbon Pools

While the TYF produces an estimate of total aboveground biomass (AGB), to model the changes of carbon within the forests, FLINTpro has incorporated 34 carbon pools (Table 6). Non-$CO_2$ gases, including methane and nitrous oxide, were not included in this analysis. In broad terms, these pools represent the tree biomass, and debris biomass. Note that soil carbon and harvested wood products were not included in this analysis.

*Tree biomass*

Tree components are modelled as a function of the AGB pool. The tree components include Stem, Bark, Leaf, and Branch, and each are calculated as a fraction of total AGB. Belowground biomass (BGB) calculated as a ratio of AGB and is further disaggregated into Coarse roots and Fine roots. The values within FLINTpro are relative to the sum of the fractions for these pools (Example for branches shown in Equation 2).

**Equation 2**

$$Branch_{Biomass} = (Branch_{Frac} / (Branch_{Frac} + Stem_{Frac} + Leaf_{Frac} + Bark_{Frac})) \times AGB$$

where:

$Branch_{Biomass}$ = The biomass allocated to Branches as part of a growth increment

$Branch_{Frac}$ = Relative fraction of aboveground biomass allocated to Branches, dimensionless

$Stem_{Frac}$ = Relative fraction of aboveground biomass allocated to Stem, dimensionless
$Leaf_{Frac}$ = Relative fraction of aboveground biomass allocated to Leaf, dimensionless
$Bark_{Frac}$ = Relative fraction of aboveground biomass allocated to Bark, dimensionless
$AGB$ = Increment in total Aboveground Biomass, Tonnes dry matter per hectare, as provided by Equation 1.

For each biomass pool, the carbon fraction can be adjusted, allowing the biomass pools to accurately reflect the carbon values. The biomass allocation fractions were sourced from the national inventory.

### *Debris Biomass*

Debris Biomass is also disaggregated into specific biomass pools (Table 6). This includes decomposable and resistant branch downed deadwood, chopped wood, bark litter, leaf litter, coarse dead root, and fine dead root. Biomass enters these pools from their source pools via turnover (natural process) and events (natural and anthropogenic). These pools then decompose at a set rate (exponential decay). The breakdown fractions for each of the pools were sourced from the national inventory. For reporting purposes, primary carbon pools are aggregated into secondary or tertiary carbon pools.

*Table 6 – Relationship between Primary, Secondary and Tertiary carbon pools.*

| Tertiary Pool | Secondary Pool | Primary Pool |
|---|---|---|
| **Atmosphere** | Atmosphere | Atmosphere |
| **Forest Carbon** | Aboveground Biomass | Stem |
| | | Branch |
| | | Bark |
| | | Leaf |
| | Belowground Biomass | Coarse Roots |
| | | Fine Roots |
| | Dead Organic Matter | Decomposable Deadwood |
| | | Decomposable Chopped Wood |
| | | Decomposable Bark Litter |
| | | Decomposable Leaf Litter |
| | | Decomposable Coarse Roots |
| | | Decomposable Fine Roots |
| | | Resistant Deadwood |
| | | Resistant Chopped Wood |
| | | Resistant Bark Litter |
| | | Resistant Leaf Litter |
| | | Resistant Coarse Roots |
| | | Resistant Fine Roots |
| **Harvested Wood Products** | Harvested Wood Products - In Use | Biofuel - In Use |
| | | Pulp and Paper - In Use |
| | | Packing wood - In Use |
| | | Furniture and Poles - In Use |
| | | Fibreboard - In Use |

| | | |
|---|---|---|
| | | Construction Wood - In Use |
| | | Mill Residue - In Use |
| | Harvested Wood Products - In Landfill | Biofuel - In Landfill |
| | | Pulp and Paper - In Landfill |
| | | Packing wood - In Landfill |
| | | Furniture and Poles - In Landfill |
| | | Fibreboard - In Landfill |
| | | Construction Wood - In Landfill |
| | | Mill Residue - In Landfill |

## 5.3. Parameters

### 5.3.1 Carbon fractions and breakdown parameters

*Table 7 - Carbon Fraction and Turnover Rates for each forest vegetation type*

| | | Carbon Fractions | | | | | | Turnover Fractions | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| id | MVG 6.0 | stem | branch | bark | leaf | c. root | fine root | branch | bark | leaf | c. root | fine root |
| 1 | Rainforests and Vine Thickets | 0.5 | 0.47 | 0.49 | 0.52 | 0.5 | 0.48 | 6.82 | 10.02 | 1.32 | 25.03 | 5.03 |
| 2 | Eucalypt Tall Open Forests | 0.5 | 0.47 | 0.49 | 0.52 | 0.5 | 0.48 | 6.82 | 10.02 | 1.32 | 25.03 | 5.03 |
| 3 | Eucalypt Open Forests | 0.5 | 0.47 | 0.49 | 0.52 | 0.5 | 0.48 | 6.82 | 10.02 | 1.32 | 25.03 | 5.03 |
| 4 | Eucalypt Low Open Forests | 0.5 | 0.47 | 0.49 | 0.52 | 0.5 | 0.48 | 6.82 | 10.02 | 1.32 | 25.03 | 5.03 |
| 5 | Eucalypt Woodlands | 0.5 | 0.47 | 0.49 | 0.52 | 0.5 | 0.48 | 6.82 | 10.02 | 1.32 | 25.03 | 5.03 |
| 6 | Acacia Forests and Woodlands | 0.5 | 0.47 | 0.49 | 0.52 | 0.5 | 0.48 | 6.82 | 10.02 | 1.32 | 25.03 | 5.03 |
| 7 | Callitris Forests and Woodlands | 0.5 | 0.47 | 0.49 | 0.52 | 0.5 | 0.48 | 30.02 | 40.02 | 2.62 | 25.03 | 5.03 |
| 9 | Melaleuca Forests and Woodlands | 0.5 | 0.47 | 0.49 | 0.52 | 0.5 | 0.48 | 6.82 | 10.02 | 1.32 | 25.03 | 5.03 |
| 10 | Other Forests and Woodlands | 0.5 | 0.47 | 0.49 | 0.52 | 0.5 | 0.48 | 6.82 | 10.02 | 1.32 | 25.03 | 5.03 |
| 11 | Eucalypt Open Woodlands | 0.5 | 0.47 | 0.49 | 0.52 | 0.5 | 0.48 | 6.82 | 10.02 | 1.32 | 25.03 | 5.03 |
| 13 | Acacia Open Woodlands | 0.5 | 0.47 | 0.49 | 0.52 | 0.5 | 0.48 | 6.82 | 10.02 | 1.32 | 25.03 | 5.03 |
| 15 | Low Closed Forests and Tall Closed Shrublands | 0.5 | 0.47 | 0.49 | 0.52 | 0.5 | 0.48 | 6.82 | 10.02 | 1.32 | 25.03 | 5.03 |
| 16 | Acacia Shrublands | 0.5 | 0.47 | 0.49 | 0.52 | 0.5 | 0.48 | 6.82 | 10.02 | 1.32 | 25.03 | 5.03 |
| 17 | Other Shrublands | 0.5 | 0.47 | 0.49 | 0.52 | 0.5 | 0.48 | 6.82 | 10.02 | 1.32 | 25.03 | 5.03 |
| 18 | Heathlands | 0.5 | 0.47 | 0.49 | 0.52 | 0.5 | 0.48 | 6.82 | 10.02 | 1.32 | 25.03 | 5.03 |
| 22 | Chenopod Shrublands, Samphire … | 0.5 | 0.47 | 0.49 | 0.52 | 0.5 | 0.48 | 6.82 | 10.02 | 1.32 | 25.03 | 5.03 |
| 26 | Unclassified native vegetation | 0.5 | 0.47 | 0.49 | 0.52 | 0.5 | 0.48 | 6.82 | 10.02 | 1.32 | 25.03 | 5.03 |
| 201 | P. radiata [1] | 0.51 | 0.514 | 0.533 | 0.511 | 0.504 | 0.484 | 30.02 | 40.02 | 2.62 | 25.03 | 5.03 |
| 207 | Hardwood [1] | 0.5 | 0.468 | 0.487 | 0.529 | 0.492 | 0.461 | 6.82 | 10.02 | 1.32 | 25.03 | 5.03 |

*Table 8 - Resistant fractions and allocations for each forest vegetation type*

| id | Resistant fractions | | | | | | Allocations | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | stem | branch | bark | leaf | coarse root | fine root | stem | branch | bark | leaf | c. root | fine root |
| 1 | 1 | 1 | 1 | 0.802 | 1 | 0.853 | 0.42 | 0.2 | 0.11 | 0.06 | 0.18 | 0.03 |
| 2 | 1 | 1 | 1 | 0.802 | 1 | 0.853 | 0.42 | 0.2 | 0.11 | 0.06 | 0.18 | 0.03 |
| 3 | 1 | 1 | 1 | 0.802 | 1 | 0.853 | 0.4 | 0.19 | 0.11 | 0.07 | 0.21 | 0.04 |
| 4 | 1 | 1 | 1 | 0.802 | 1 | 0.853 | 0.49 | 0.11 | 0.09 | 0.04 | 0.24 | 0.03 |
| 5 | 1 | 1 | 1 | 0.802 | 1 | 0.853 | 0.31 | 0.2 | 0.08 | 0.11 | 0.23 | 0.07 |
| 6 | 1 | 1 | 1 | 0.802 | 1 | 0.853 | 0.28 | 0.19 | 0.07 | 0.12 | 0.25 | 0.09 |
| 7 | 1 | 1 | 1 | 0.892 | 1 | 0.853 | 0.28 | 0.22 | 0.08 | 0.07 | 0.27 | 0.08 |
| 9 | 1 | 1 | 1 | 0.802 | 1 | 0.853 | 0.31 | 0.2 | 0.08 | 0.11 | 0.23 | 0.07 |
| 10 | 1 | 1 | 1 | 0.802 | 1 | 0.853 | 0.31 | 0.2 | 0.08 | 0.11 | 0.24 | 0.07 |
| 11 | 1 | 1 | 1 | 0.802 | 1 | 0.853 | 0.29 | 0.19 | 0.07 | 0.12 | 0.25 | 0.09 |
| 12 | 1 | 1 | 1 | 0.802 | 1 | 0.853 | 0.31 | 0.16 | 0.08 | 0.08 | 0.28 | 0.09 |
| 13 | 1 | 1 | 1 | 0.802 | 1 | 0.853 | 0.27 | 0.19 | 0.07 | 0.12 | 0.25 | 0.1 |
| 15 | 1 | 1 | 1 | 0.802 | 1 | 0.853 | 0.31 | 0.2 | 0.08 | 0.11 | 0.24 | 0.07 |
| 16 | 1 | 1 | 1 | 0.802 | 1 | 0.853 | 0.28 | 0.19 | 0.07 | 0.12 | 0.25 | 0.1 |
| 17 | 1 | 1 | 1 | 0.802 | 1 | 0.853 | 0.29 | 0.19 | 0.07 | 0.12 | 0.25 | 0.09 |
| 18 | 1 | 1 | 1 | 0.802 | 1 | 0.853 | 0.35 | 0.21 | 0.09 | 0.1 | 0.21 | 0.04 |
| 22 | 1 | 1 | 1 | 0.802 | 1 | 0.853 | 0.33 | 0.2 | 0.08 | 0.11 | 0.22 | 0.06 |
| 26 | 1 | 1 | 1 | 0.802 | 1 | 0.853 | 0.26 | 0.2 | 0.07 | 0.12 | 0.28 | 0.08 |
| 201 | 1 | 1 | 1 | 0.892 | 1 | 0.853 | 0.473 | 0.136 | 0.064 | 0.086 | 0.209 | 0.032 |
| 207 | 1 | 1 | 1 | 0.802 | 1 | 0.853 | 0.408 | 0.19 | 0.072 | 0.106 | 0.193 | 0.031 |

*Table 9 - Breakdown fractions expressed as ½ life years for each forest vegetation type*

| Id | Decomposable | | | | | | Resistant | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dead wood | chopped wood | bark litter | leaf litter | coarse dead root | fine dead root | Dead wood | chopped wood | bark litter | leaf litter | coarse dead root | fine dead root |
| 1 | 0 | 0 | 0 | 0.0772 | 0 | 0.00013 | 4.5002 | 4.5002 | 3.5002 | 1.1752 | 3.0003 | 0.00013 |
| 2 | 0 | 0 | 0 | 0.0772 | 0 | 0.00013 | 4.5002 | 4.5002 | 3.5002 | 1.1752 | 3.0003 | 0.00013 |
| 3 | 0 | 0 | 0 | 0.0772 | 0 | 0.00013 | 4.5002 | 4.5002 | 3.5002 | 1.1752 | 3.0003 | 0.00013 |
| 4 | 0 | 0 | 0 | 0.0772 | 0 | 0.00013 | 4.5002 | 4.5002 | 3.5002 | 1.1752 | 3.0003 | 0.00013 |
| 5 | 0 | 0 | 0 | 0.0772 | 0 | 0.00013 | 4.5002 | 4.5002 | 3.5002 | 1.1752 | 3.0003 | 0.00013 |
| 6 | 0 | 0 | 0 | 0.0772 | 0 | 0.00013 | 4.5002 | 4.5002 | 3.5002 | 1.1752 | 3.0003 | 0.00013 |
| 7 | 0 | 0 | 0 | 0.28012 | 0 | 0.00013 | 5.0002 | 5.0002 | 4.5002 | 2.9972 | 3.0003 | 0.00013 |
| 9 | 0 | 0 | 0 | 0.0772 | 0 | 0.00013 | 4.5002 | 4.5002 | 3.5002 | 1.1752 | 3.0003 | 0.00013 |
| 10 | 0 | 0 | 0 | 0.0772 | 0 | 0.00013 | 4.5002 | 4.5002 | 3.5002 | 1.1752 | 3.0003 | 0.00013 |
| 11 | 0 | 0 | 0 | 0.0772 | 0 | 0.00013 | 4.5002 | 4.5002 | 3.5002 | 1.1752 | 3.0003 | 0.00013 |
| 12 | 0 | 0 | 0 | 0.0772 | 0 | 0.00013 | 4.5002 | 4.5002 | 3.5002 | 1.1752 | 3.0003 | 0.00013 |
| 13 | 0 | 0 | 0 | 0.0772 | 0 | 0.00013 | 4.5002 | 4.5002 | 3.5002 | 1.1752 | 3.0003 | 0.00013 |
| 15 | 0 | 0 | 0 | 0.0772 | 0 | 0.00013 | 4.5002 | 4.5002 | 3.5002 | 1.1752 | 3.0003 | 0.00013 |
| 16 | 0 | 0 | 0 | 0.0772 | 0 | 0.00013 | 4.5002 | 4.5002 | 3.5002 | 1.1752 | 3.0003 | 0.00013 |
| 17 | 0 | 0 | 0 | 0.0772 | 0 | 0.00013 | 4.5002 | 4.5002 | 3.5002 | 1.1752 | 3.0003 | 0.00013 |
| 18 | 0 | 0 | 0 | 0.0772 | 0 | 0.00013 | 4.5002 | 4.5002 | 3.5002 | 1.1752 | 3.0003 | 0.00013 |
| 22 | 0 | 0 | 0 | 0.0772 | 0 | 0.00013 | 4.5002 | 4.5002 | 3.5002 | 1.1752 | 3.0003 | 0.00013 |
| 26 | 0 | 0 | 0 | 0.0772 | 0 | 0.00013 | 4.5002 | 4.5002 | 3.5002 | 1.1752 | 3.0003 | 0.00013 |
| 201 | 0 | 0 | 0 | 0.28012 | 0 | 0.00013 | 5.0002 | 5.0002 | 4.5002 | 2.9972 | 3.0003 | 0.00013 |

| Id | Decomposable | | | | | | Resistant | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dead wood | chopped wood | bark litter | leaf litter | coarse dead root | fine dead root | Dead wood | chopped wood | bark litter | leaf litter | coarse dead root | fine dead root |
| 207 | 0 | 0 | 0 | 0.0772 | 0 | 0.00013 | 4.5002 | 4.5002 | 3.5002 | 1.1752 | 3.0003 | 0.00013 |

*Table 10 - Breakdown fractions expressed as ½ life years of products for each forest vegetation type*

| id | paper and pulp in use | packing wood in use | furniture in use | fibreboard in use | construction in use | mill residue in use | biofuel burnt for bio energy |
|---|---|---|---|---|---|---|---|
| 1 | 0.292893 | 0.027345 | 0.027345 | 0.027345 | 0.019609 | 1 | 1 |
| 2 | 0.292893 | 0.027345 | 0.027345 | 0.027345 | 0.019609 | 1 | 1 |
| 3 | 0.292893 | 0.027345 | 0.027345 | 0.027345 | 0.019609 | 1 | 1 |
| 4 | 0.292893 | 0.027345 | 0.027345 | 0.027345 | 0.019609 | 1 | 1 |
| 5 | 0.292893 | 0.027345 | 0.027345 | 0.027345 | 0.019609 | 1 | 1 |
| 6 | 0.292893 | 0.027345 | 0.027345 | 0.027345 | 0.019609 | 1 | 1 |
| 7 | 0.292893 | 0.027345 | 0.027345 | 0.027345 | 0.019609 | 1 | 1 |
| 9 | 0.292893 | 0.027345 | 0.027345 | 0.027345 | 0.019609 | 1 | 1 |
| 10 | 0.292893 | 0.027345 | 0.027345 | 0.027345 | 0.019609 | 1 | 1 |
| 11 | 0.292893 | 0.027345 | 0.027345 | 0.027345 | 0.019609 | 1 | 1 |
| 12 | 0.292893 | 0.027345 | 0.027345 | 0.027345 | 0.019609 | 1 | 1 |
| 13 | 0.292893 | 0.027345 | 0.027345 | 0.027345 | 0.019609 | 1 | 1 |
| 15 | 0.292893 | 0.027345 | 0.027345 | 0.027345 | 0.019609 | 1 | 1 |
| 16 | 0.292893 | 0.027345 | 0.027345 | 0.027345 | 0.019609 | 1 | 1 |
| 17 | 0.292893 | 0.027345 | 0.027345 | 0.027345 | 0.019609 | 1 | 1 |
| 18 | 0.292893 | 0.027345 | 0.027345 | 0.027345 | 0.019609 | 1 | 1 |
| 22 | 0.292893 | 0.027345 | 0.027345 | 0.027345 | 0.019609 | 1 | 1 |
| 26 | 0.292893 | 0.027345 | 0.027345 | 0.027345 | 0.019609 | 1 | 1 |
| 201 | 0.292893 | 0.027345 | 0.027345 | 0.027345 | 0.019609 | 1 | 1 |
| 207 | 0.292893 | 0.027345 | 0.027345 | 0.027345 | 0.019609 | 1 | 1 |

# 6. References


ABARES 2021, Catchment Scale Land Use of Australia – Update December 2020, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra, February, CC BY 4.0, DOI: 10.25814/aqjw-rq15

Kesteven, J.L., J. Landsberg, and URS Australia. 2004. *Developing a National Forest Productivity Model: National Carbon Accounting System, Technical Report No.23.* Department of Climate Change, Australian Government, Canberra.

Landsberg, J.J., and R.H. Waring. 1997. 'A Generalised Model of Forest Productivity Using Simplified Concepts of Radiation-Use Efficiency, Carbon Balance and Partitioning'. *Forest Ecology and Management* 95 (3): 209–28. https://doi.org/10.1016/S0378-1127(97)00026-1.

Paul, Keryn I., Stephen H. Roxburgh, and Jacqueline R. England. 2022. 'Sequestration of Carbon in Commercial Plantations and Farm Forestry'. *Trees, Forests and People* 9 (September): 100284. https://doi.org/10.1016/j.tfp.2022.100284.

Roxburgh SH, Karunaratne SB, Paul KI, Lucas RM, Armston JD, Sun J. 2019. A revised above-ground maximum biomass layer for the Australian continent. Forest Ecology and Management. 432:264–275. https://doi.org/10.1016/j.foreco.2018.09.011

Snowdon, Peter. 2002. 'Modeling Type 1 and Type 2 Growth Responses in Plantations after Application of Fertilizer or Other Silvicultural Treatments'. *Forest Ecology and Management* 163 (1–3): 229–44. https://doi.org/10.1016/S0378-1127(01)00582-5.

Waterworth, R.M., G.P. Richards, C.L. Brack, and D.M.W. Evans. 2007. 'A Generalised Hybrid Process-Empirical Model for Predicting Plantation Forest Growth'. *Forest Ecology and Management* 238 (1–3): 231–43. https://doi.org/10.1016/j.foreco.2006.10.014.