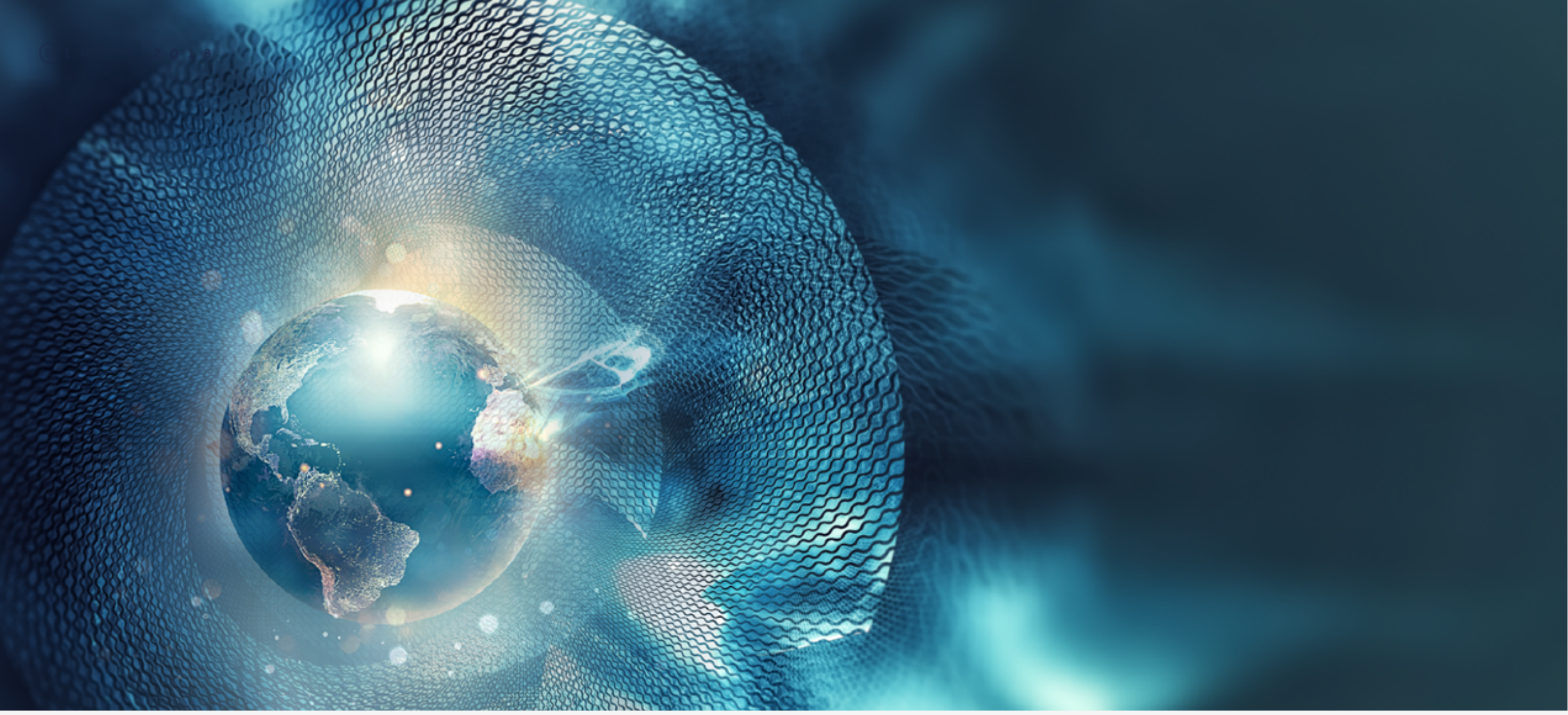

Permanent Timber Production Zone Land

Forest Carbon Assessment

January 2024

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Contents

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
STT	Sustainable Timber Tasmania
TYF	Tree Yield Formula

Executive Summary

Sustainable Timber Tasmania manages over 800,000 ha of public land in Tasmania. Of this, approximately 627,000 ha is native forest, 107,000 ha is plantation forest (over 80,000 ha of which the forestry right has been sold but STT maintains the carbon right) and 78,000 ha is non-forest.

The Mullion Group was engaged by Sustainable Timber Tasmania (STT) to model forest carbon changes through time across native forests and plantations on permanent timber production zone land (PTPZL) and harvested wood products, using the FLINTpro system. Note that only areas classified as forest in the national forest data at least once between 1990 and 2022 were modelled. The results of the simulation indicate that forest carbon stocks in aboveground biomass, belowground biomass, and dead organic matter have remained relatively steady over the time-period, with an estimated 157.1 Mt C on PTPZL in 2022 and 3.5 Mt C in harvested wood in use (Figure 1). An estimation of harvested wood products in landfill was calculated, based on simplified assumptions around how much product is diverted to landfill each year. In 2022, the carbon stock in landfill was estimated to be 3.08 Mt C and is increasing by approximately 1.7% per year. Changes in carbon were primarily driven by harvesting events, fire and subsequent regrowth, both in native forests and plantations, which can be seen in the spatial outputs (Figure 2).

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

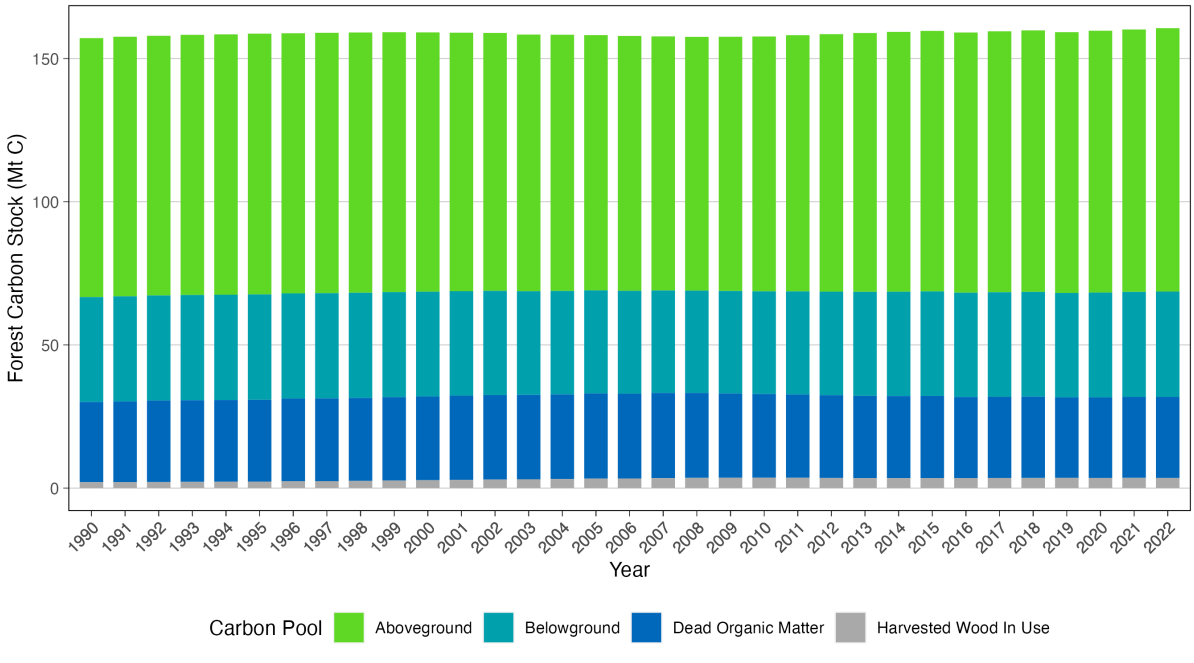

Figure 1 – Estimates of forest carbon stock (Mt C) on the current PTPZL extent 1990-2022, incorporating aboveground biomass, belowground biomass, dead organic matter and harvested wood in use. Note that this includes native forest and plantations, but not non-forest land (note that this does not include the carbon in harvested wood products in landfill).

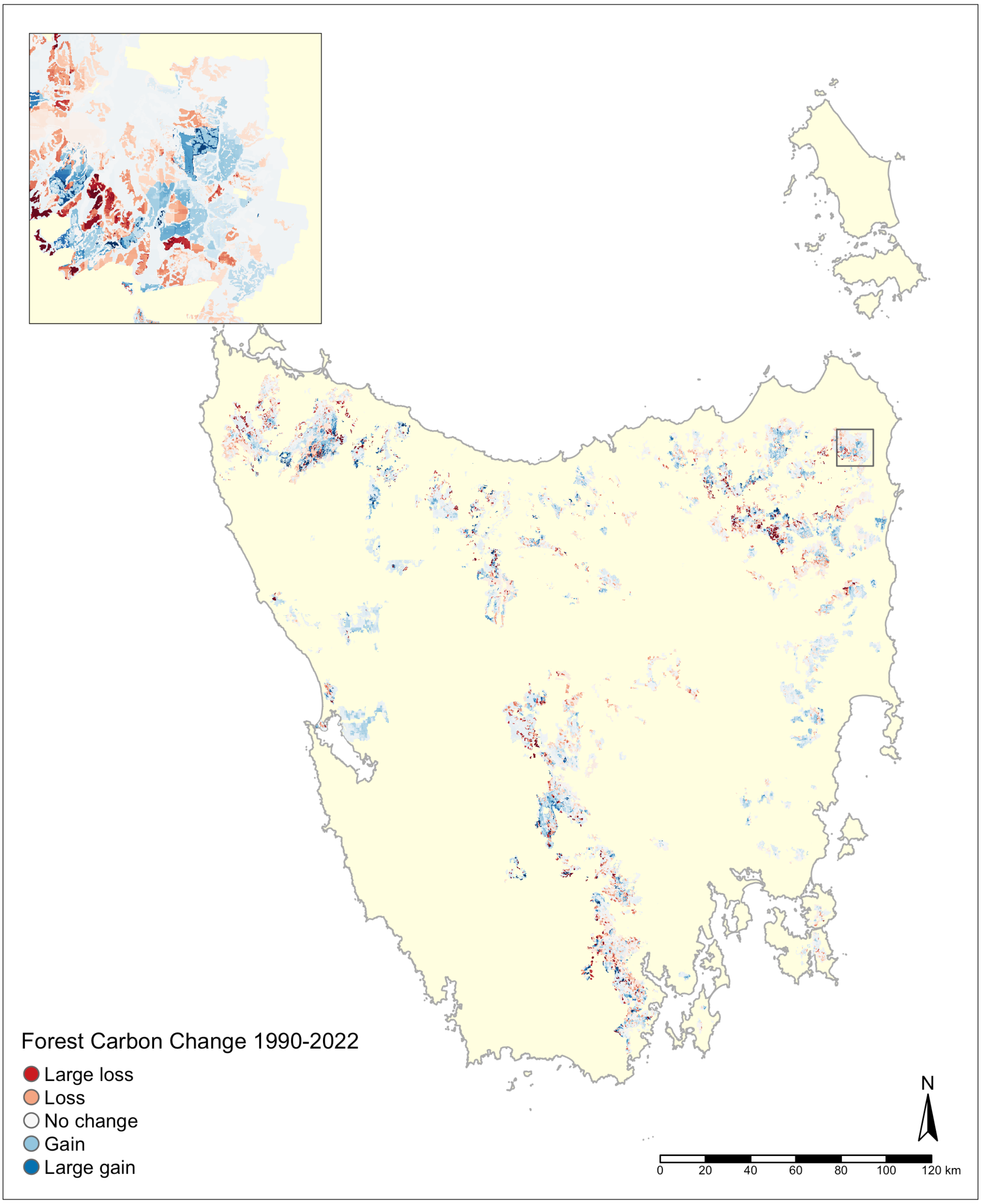

Figure 2 - Spatial output indicating the areas where forest carbon has increased (blue) and decreased (red) across PTPZL between 1990 and 2022. A zoomed in inset map of an area in the northeast is also shown.

1. Introduction

This report presents the methods and results of a baseline carbon assessment undertaken using the FLINTpro software across the Sustainable Timber Tasmania (STT) permanent timber production zone land (PTPZL). The assessment was undertaken across current production native forests, and softwood and hardwood plantations; it excludes areas of non-forest.

The assessment was based on modelling system that aims to accurately 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 in 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 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 all processes and events that occur within STT managed forests, 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 environment.

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 3). 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.

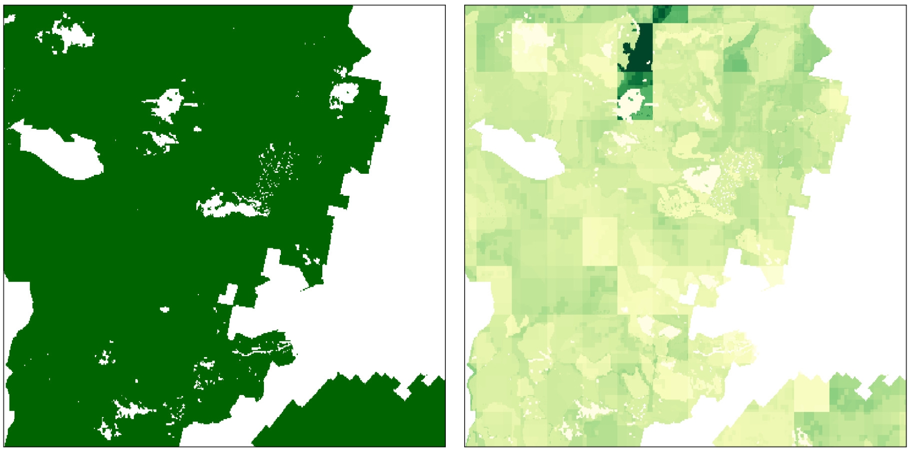

Figure 3 - In FLINTpro, the land cover products delineating forest extent (left) are integrated with forest growth models to produce estimates of carbon stock (right) and stock changes over time.

In this project, FLINTpro was used to model the changes in forest carbon across all forests in Tasmania managed by STT. A conceptual framework for the modelling system is shown in Figure 4. Two main drivers of change were modelled: processes, such as forest growth; and events, such as fire and timber harvesting. Processes and events are triggered by spatial data and use rules and parameters defined in aspatial (tabular) data.

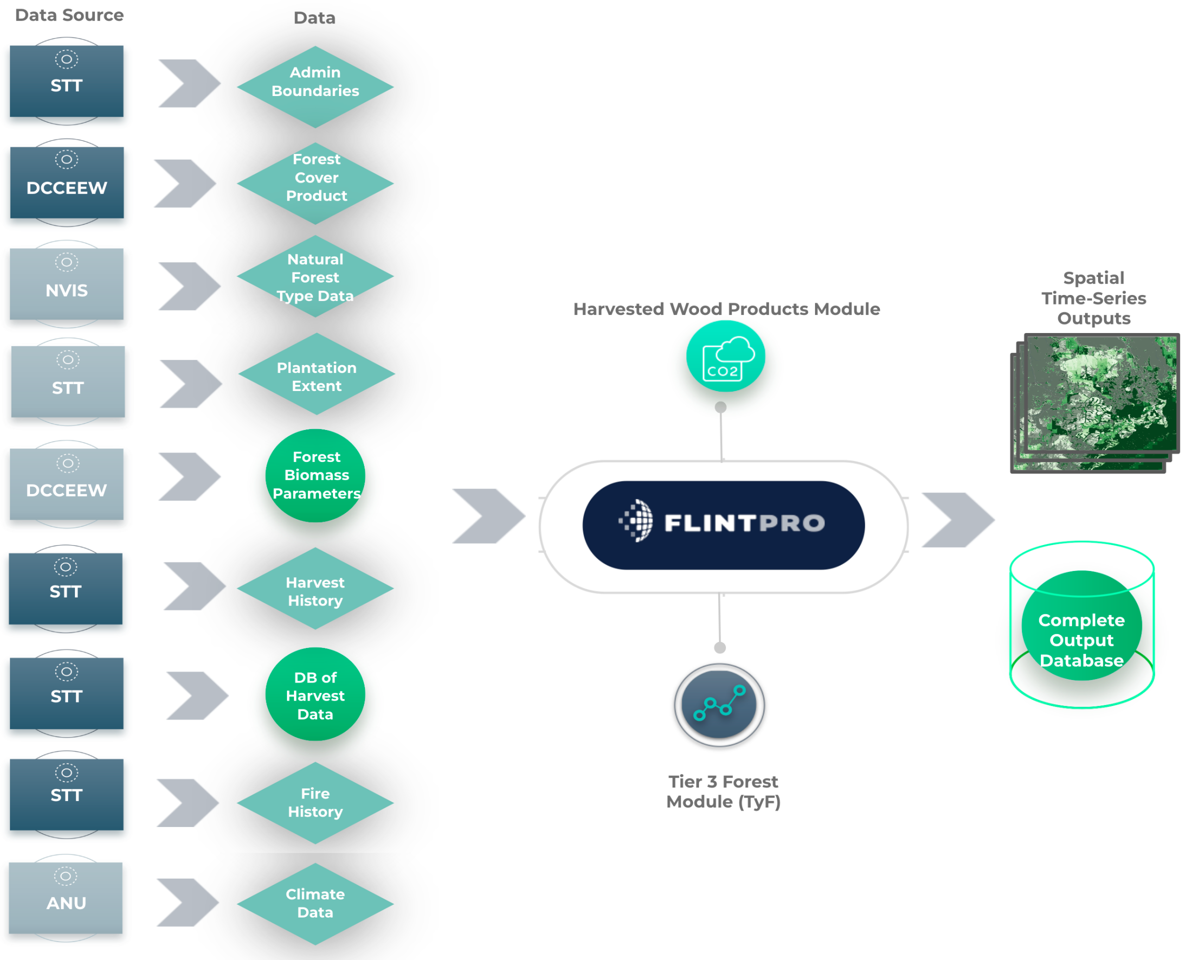

Figure 4 - Conceptual framework for the Sustainable Timber Tasmania (STT) simulation. The simulation used data principally supplied by STT, along with inputs from the Commonwealth Department of Climate Change, Energy, the Environment and Water (DCCEEW) and Australian National University (ANU).

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., plantations versus native forests).

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 which fraction is converted to harvested wood products (HWP). Breakdown fractions for harvested wood products are also defined in aspatial data.

In this project, aspatial data for harvest types and allocation of carbon fractions were provided by STT and align with those used in the National Greenhouse Gas Inventory (NGGI)[1]. Other parameters and assumptions were sourced directly from the methods used in the NGGI.

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

Table 1. Spatial Input Data.

Type	Data	Source	Resolution	Description
Static	Simulation Area	STT	Vector	Polygon dataset consisting of Permanent Timber Production Zone Land (PTPZL).
Time-series	Forest Cover	DCCEEW	0.00025 degrees* (~25 m pixels)	National Forest and Sparse Woody Vegetation Data (Version 6.0 - 2021 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 2021 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 5.1. 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).
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	STT	0.00025 degrees	History of planned burns and wildfires in Tasmania from 1961 onwards. Converted from vector to raster.
Time-series	Harvest Data	STT	0.00025 degrees	Harvest history in the STT estate, with earliest records beginning in 1901. Five harvest types prior to 2003 and 23 after. Converted from vector to raster.
Time-series	Plantation	STT	0.00025 degrees	STT provided plantation extents for the years 1990 and 2023 with hardwood and softwood codes. 1990 used as 1920 and 2023 used as 1991 in the time series.
Static	NPI Region	ABARES (2016)	Vector	NA

* 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 5.1 Filter	Australia - Present Major Vegetation Groups - NVIS Version 5.1.
Static	Always woody	DCCEEW	Australia-Always woody between 1989 and 2021	This layer is derived from the National Forest and Sparse Woody Vegetation data and shows areas which are classified as either forest or sparse woody for the whole time-series (1989-2021)
Static	Plantation extent 1990	STT	STT Plantation Extent 2023	Extent of softwood and hardwood plantations in 2023
Static	Plantation extent 2023	STT	STT Plantation Extent 1990	Extent of softwood and hardwood plantations in 1990
Static	Simulation Area	STT	STT Simulation Area	Polygon dataset consisting of Permanent Timber Production Zone Land (PTPZL).

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 10 in the Appendix)
- Resistant fractions and forest component allocations (Table 11 in the Appendix)
- DOM Breakdown fractions (Table 12 in the Appendix)
- Breakdown fractions for harvested wood products (Table 13 in the Appendix)

The locations of the different forest vegetation types were defined by the Major Vegetation Groups (MVG) layer (Figure 5). 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's data.

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

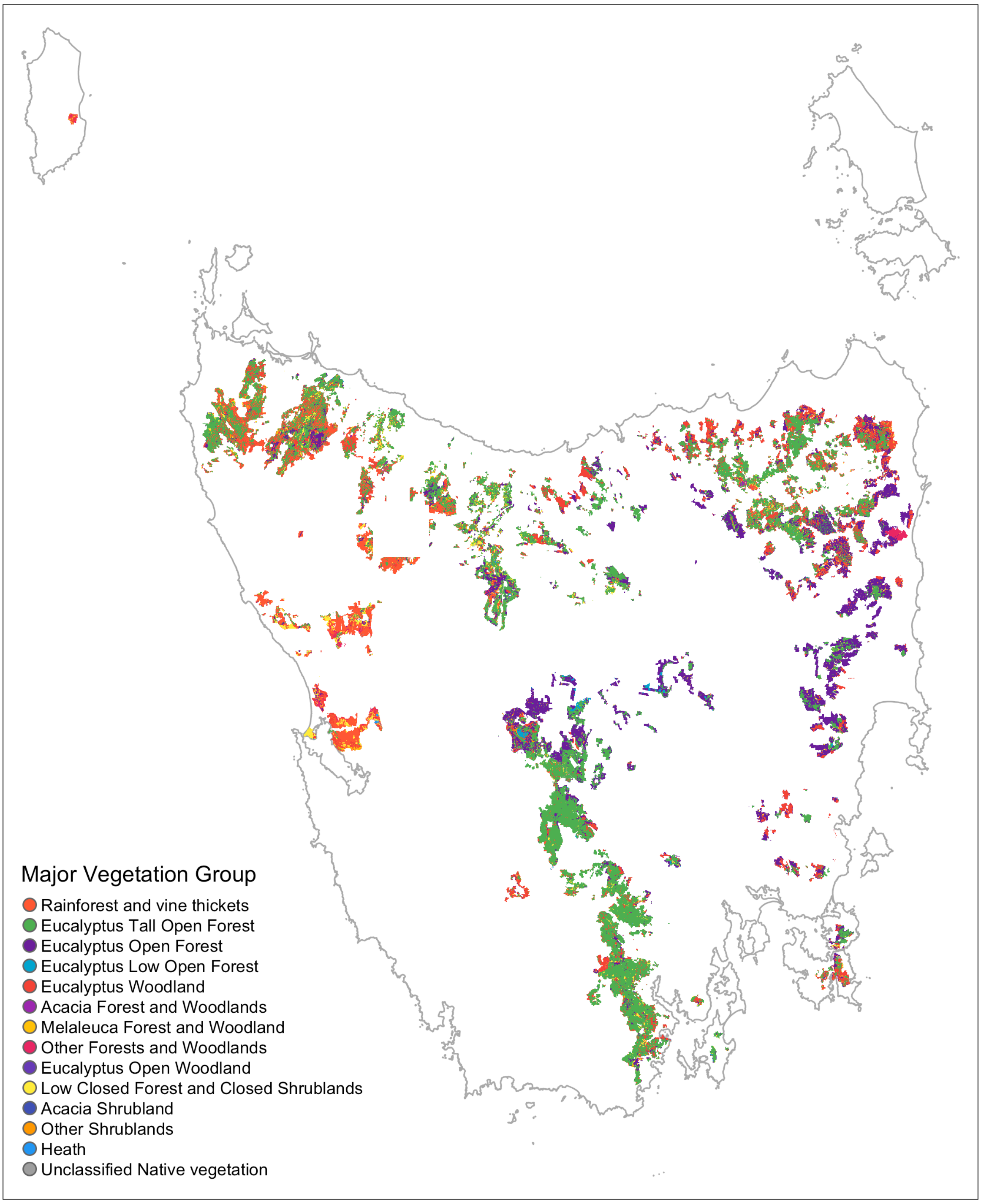

Figure 5 - Major Vegetation Groups in PTPZL. Based on the National Vegetation Information System MVG 5.1 data

2.1.2. Fire history

Fire history data was provided by STT as an annual raster time-series, with the first events starting in 1961. The data contained three fire types: wildfire, prescribed fire and unknown. The unknown category was treated as wildfire for the purposes of this simulation.

2.1.3. Timber Harvesting

STT provided harvesting information for 23 different harvest types (Table 3). The data was provided as a raster time series, with the earliest event records being in 1901. Prior to 2003, only the first 5 harvest types exist in the data.

Table 3 - Harvest types provided by Sustainable Timber Tasmania

Spatial code	Harvest Type
1	PART - Partial harvest
2	CLF - Clearfell
3	HW - Hardwood plantation
4	SF - Softwood plantation
5	CLTN - Clearfell and thinned
6	AGR - Advanced growth retention
7	ARN - Variable (aggregated) retention
8	PSR - Potential sawlog retention
9	PSW - PSR wattle removal
10	SED - Seed tree retention
11	STX - Seed tree removal
12	SW1 - Shelterwood retention
13	SW2 - Shelterwood removal
14	THN - Commercial thinning of native forest (*same parameters as PSR)
15	USR - Special species sawlog harvesting (*same parameters as AGR)
16	ECF - Early clearfell
17	OTS - Salvage fire killed other
18	CTP1 - Plantation 1st commercial thinning
19	CPT2 - Plantation 2nd commercial thin
20	POST - Plantation thinning for posts
21	SCWT - Softwood Clearwood Thinning
22	SKC1 - Softwood thinning
23	DRN - Dispersed retention

2.1.4. Plantation history

STT provided two plantation extent layers for use in this project: one from 1990 and one from 2023 (Figure 6). Each layer contained two plantation types: softwood and hardwood. The 1990 layer was mapped to 1920 (simulation start date) and the 2023 layer was mapped to 1991. This provided a means to address plantation transitions, so that clearing events, triggered by either the harvest history data or the national forest cover data, which occurred in native forest and intersected with the 2023 plantation extent, were replanted as a plantation.

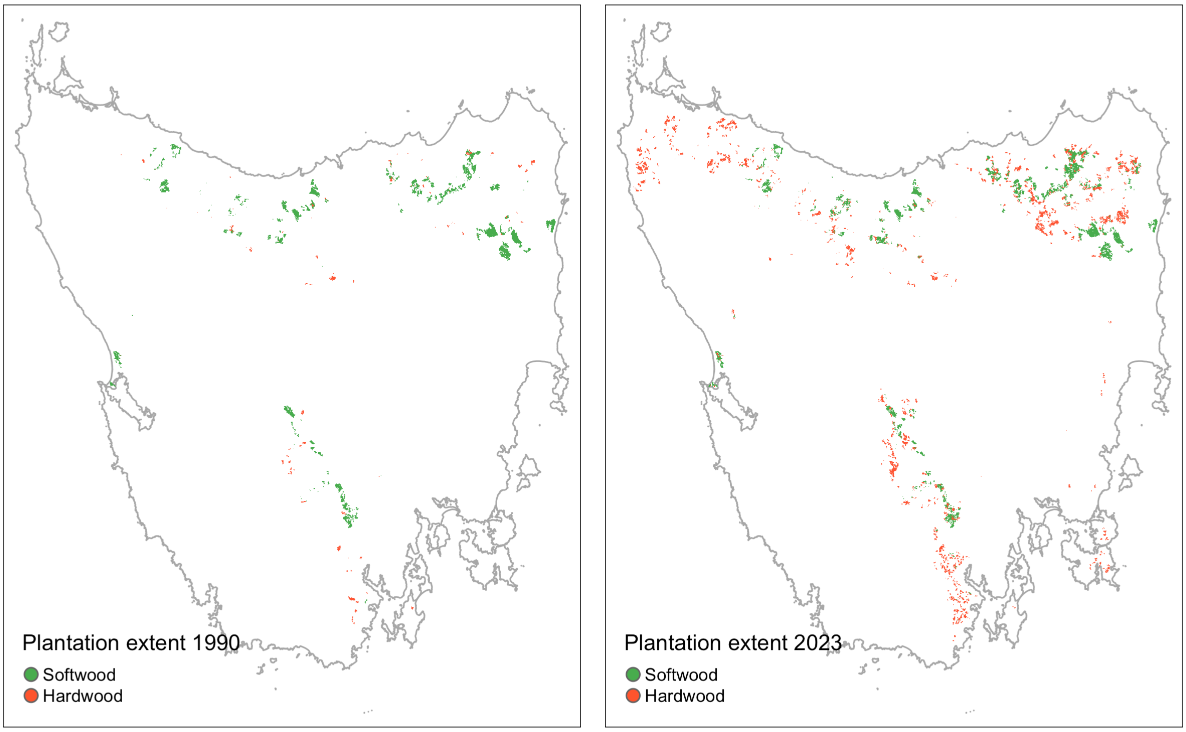

Figure 6 - Hardwood and softwood plantation extents for 1990 (left) and 2023 (right)

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 due to insufficient and unreliable data inputs. Differences are also likely related to assumptions made in this simulation around harvest events and plantation transitions and spatial inconsistences between datasets (see Table 4 & Table 5).

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 1920 to 2022 to allow a 'spin up' period. Areas which were plantation in the 1990 plantation extent were planted in 1975 for softwood and 1980 for hardwood. This meant that plantations were approximately half-way through their rotations in 1990. The exception to this were areas which had a plantation harvest event prior to 1975. In this case the plant event was set two years after the harvest event.

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 (5.2.1). 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. The annual FPI data was supplied by DCCEEW via STT for use in this simulation. Forest growth is controlled slightly differently in native systems compared with plantations. This is based on an assumption that plantations have slightly higher growth rates because of management inventions. This is explained further in the Appendix (5.2.1).

Note that softwood plantations were considered to be *Pinus radiata* in this simulation, while hardwood plantations were given generic hardwood parameters.

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 STT simulation, the main events that were modelled related to timber harvesting of both native and plantation forests. In addition, fire events (wildfire and prescribed) and reforestation events in plantation areas were also modelled. Clearing and regrowth events triggered by the national forest cover product in native forests were not included, as per the NGGI methods (pers comm., STT, 30/03/2023). However, areas of forest cover loss that are created from timber harvesting are accounted for through the harvest event data. In plantations, clearing and regrowth events triggered by the national forest cover product were applied, but only when there was no corresponding harvest event in the harvest data. Table 4 shows the range of potential forest transitions relevant to STT and how they were managed in FLINTpro.

Table 4. Event transitions and how they were implemented in FLINTpro

Transition	Event triggers	Implementation
Native forest – Non-forest	Forest cover data	No event (ignored)
Non-forest – Native forest	Forest cover data	No event (ignored)
Native forest to plantation	Plantation in 2023 layer but not in 1990 layer. Transition triggered by harvest data and/or forest cover data.	If harvest event type was either clearfell or plantation, then a harvest event on 100% of the forest was applied, followed by a replant 2 years later. If triggered by the forest cover data, the replant is based on a subsequent gain in the forest cover data.
Plantation to native forest	Plantation in 1990 layer, but not in 2023 layer, triggered by harvest event and/or forest cover data.	Plantation harvest applied; re-plant of native forest triggered by forest cover data
Plantation to non-forest	Triggered by harvest or forest cover data	Clearing, no product recovery

Plantation to plantation	Triggered by harvest or harvest data	Plantation harvested, replanted two years later
Non-forest to plantation	Triggered by forest cover data	Plantation planted based on gain in forest cover data
Hardwood to softwood plantation	Hardwood in 1990 layer, softwood in 2023 layer, triggered by harvest event.	Harvest hardwood, plant softwood two years later
Softwood to hardwood plantation	Softwood in 1990 layer, hardwood in 2023 layer, triggered by harvest event.	Harvest softwood, plant hardwood two years later

Harvest

As described earlier (Table 3), STT provided data for 23 different harvest types. It should be noted though, that many of the harvest types have the same carbon fraction and allocation parameters, so are effectively treated the same by the system. Harvest parameters (as provided by STT) are shown here in Table 9 in the Appendix. Note that the fraction affected for plantation harvests was changed from 0.95 to 1 to allow replant events and plantation transitions to occur. A replant event 2 years after a plantation harvest was automatically applied (as instructed by STT). There were many inconsistencies between the provided harvest and plantation spatial information, so assumptions and rules were made to address these (Table 5).

Table 5 - Inconsistencies between plantation and harvest data

Issue	Solution
Spatial boundary misalignments between harvest areas and plantation areas	Plantation harvests were only applied outside of the plantation extent if they coincided with a forest loss event in the forest cover data
Plantation harvests of native forest	As above, these were treated as plantation harvests if there was a forest loss event in the forest cover data
Clearfell harvests on plantations	These were treated as plantation harvests, given that the parameters provided by STT were the same for both harvest type
Hardwood harvest on softwood plantation or vice versa	Preference was given to the plantation extent layer, as it was assumed this was more accurate than the harvesting data

Fire

Fire is an important event type in the Australian context and is integral to much of Australia's forest ecology. Fire results in the combustion of aboveground biomass and dead organic matter pools, as well as the conversion of living biomass to dead biomass. For this project fire was modelled as being either natural wildfire or hazard reduction burning. Data on timing and extent of both fire types was provided by STT as a time series from 1961 onwards. The 'unknown' fire category in the data was treated as wildfire for the purposes of the simulation. Fires in the southern hemisphere are usually recorded against a fire season (e.g., 2019-2020), rather than a specific year. For this simulation fires were assigned to the latter year (e.g., 2020).

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; 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 NGGI. 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 6). Note that in this simulation, the root mass of trees is not affected by fires.

Table 6 - 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 filters

FLINTpro was configured with a number of output filters, which enable the results to be explored in more detail based on different categories. The filters can be used to query the results based on spatial subsets or aggregations (e.g., only softwood plantations in 2023). The output filters used in this simulation include:

- Major Vegetation Groups
- Always woody between 1989 and 2021
- Plantation extent 1990 (with hardwood and softwood classes)
- Plantation extent 2023 (with hardwood and softwood classes)

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, dead organic matter and harvested wood products in use. The system also assigns a flux type to each movement of carbon. The flux types used here included:

- Wildfire
- Prescribed fire
- Harvest
- Clearing
- Turnover
- Net primary productivity
- Plant trees

- Decomposition

This set-up enables specific fluxes and their associated causes to be analysed in detail. Note that post-processing of the HWP to atmosphere fluxes were undertaken at the request of STT to account for the portion of the flux that diverts to landfill instead of the atmosphere. The ratio of the flux from the HWP pool to atmosphere versus landfill used here was 67:33. This was determined through an analysis of HWP flux data from the FLINTpro modelling, production data from the Tasmanian State of the Forests Report 2022, and waste data from the DCCEEW National Waste Report 2022. While this number is in line with what the authors expect, and a deliberately conservative estimate relative to other empirical studies (Ximenes, et al 2017), it is recognised that more research is required to quantify a more precise ratio. The fraction of the HWP flux to landfill (i.e., 33%) was then split 60:40 into paper and wood products, with 48% of the paper proportion and 10% of the wood proportion being sent to the atmosphere. This represents the decay rates from landfill to the atmosphere, as used by the NGGI. The remaining proportions are assumed to stay in landfill indefinitely.

3. Outputs and results

As described above, changes in forest carbon stock within the STT estate are driven by processes and events triggered by spatially and temporally explicit datasets. In the native forest estate, forest cover losses are only triggered by the harvesting or fire datasets. Any forest cover losses in the national forest cover data are effectively ignored, which is consistent with the NGGI (pers comm., STT, 30/03/2023). It is implemented this way in the national inventory under the assumption that loss events in the native production estate are due to management actions. This also helps to avoid spatial and temporal conflicts between the two datasets (i.e., harvest history and forest cover). However, in the plantation estate, forest cover loss and gain events triggered by the forest cover data were included, and thus the carbon changes associated with these events are tracked.

In the following results, only carbon in the aboveground (AGB), belowground (BGB), dead organic matter (DOM) and harvested wood products (HWP) in use pools are shown. Note that soil carbon is not included in this analysis.

Overall forest carbon stocks (AGB, BGB, DOM and HWP in use) across the STT PTPZL for the period 1990-2022 are shown in Figure 7. Overall forest carbon stocks in AGB, BGB and DOM in 2022 were 157.1 Mt C, which is 2.0 Mt greater than in 1990 (155.1 Mt C). Carbon stocks in HWP were 2.08 Mt C in 1990 and 3.55 Mt C in 2022.

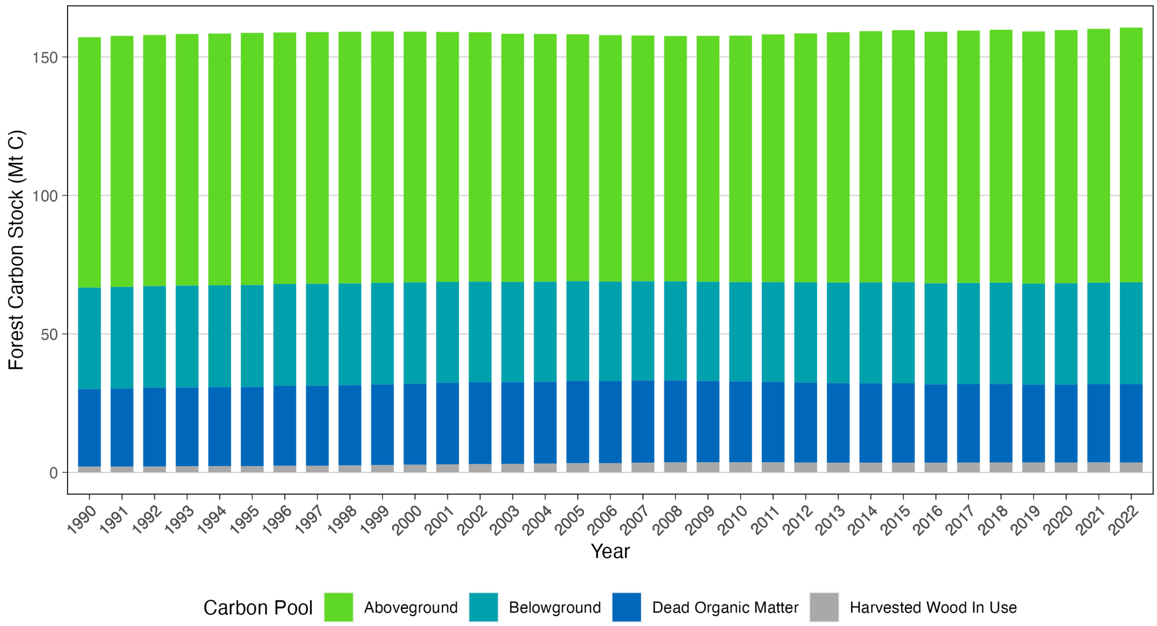

Figure 7 - Estimates of forest carbon stock (Mt C) across PTPZL from 1990-2022, incorporating aboveground biomass, belowground biomass, dead organic matter and harvested wood products in use.

Carbon stocks for HWP in use and HWP estimated to be in landfill are also shown in Figure 8. As explained earlier (Section 2.2.4), HWP in landfill was estimated by post-processing the output data to divert a portion (33%) of the 'HWP to atmosphere' flux to landfill. In 2022, the estimated HWP in landfill was 3.08 Mt C. This carbon pool is growing by a rate of approximately 1.7% per year.

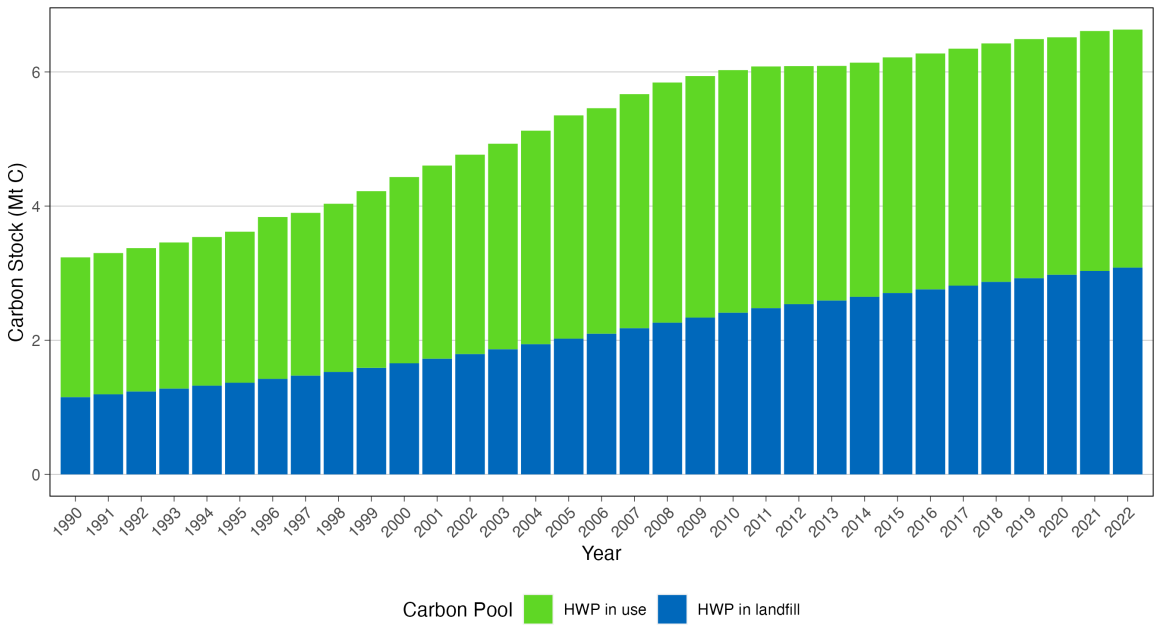

Figure 8 - Estimates of forest carbon stock (Mt C) in harvested wood products (HWP) in use and HWP in landfill, extracted from PTPZL from 1990-2022.

A map of forest carbon across the STT estate in 2022 is shown in Figure 9. Note that high values in non-disturbed areas are largely driven by the national maximum biomass (M) layer (Roxburgh et.al, 2019), as discussed in Section 2.2.1.

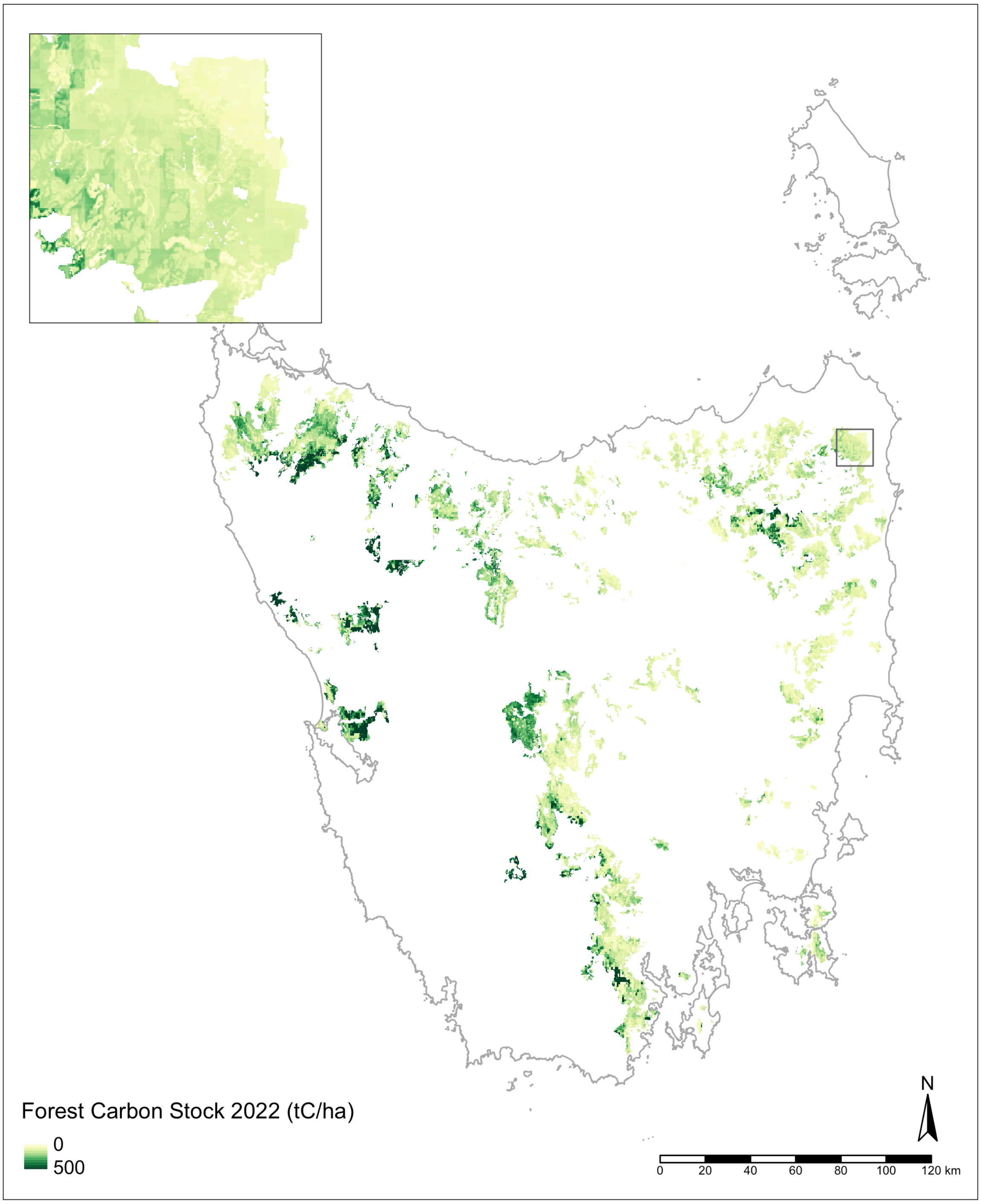

Figure 9 - Spatial output of forest carbon for 2022, including aboveground biomass, belowground biomass and dead organic matter. A zoomed in inset map of an area in the northeast is also shown.

Carbon stocks over time for the forests in the current plantation extent are shown in Figure 10. Note that this includes areas which were native forest in 1990 but converted to plantations at some point between 1990 and 2022. This shows stocks in hardwood areas decreased from 2000 to 2009 before increasing to the present day. This reflects the conversion of native forests to hardwood plantations across this period. Figure 11 shows the carbon stocks over time in native forests only (i.e., not including the current plantation extent).

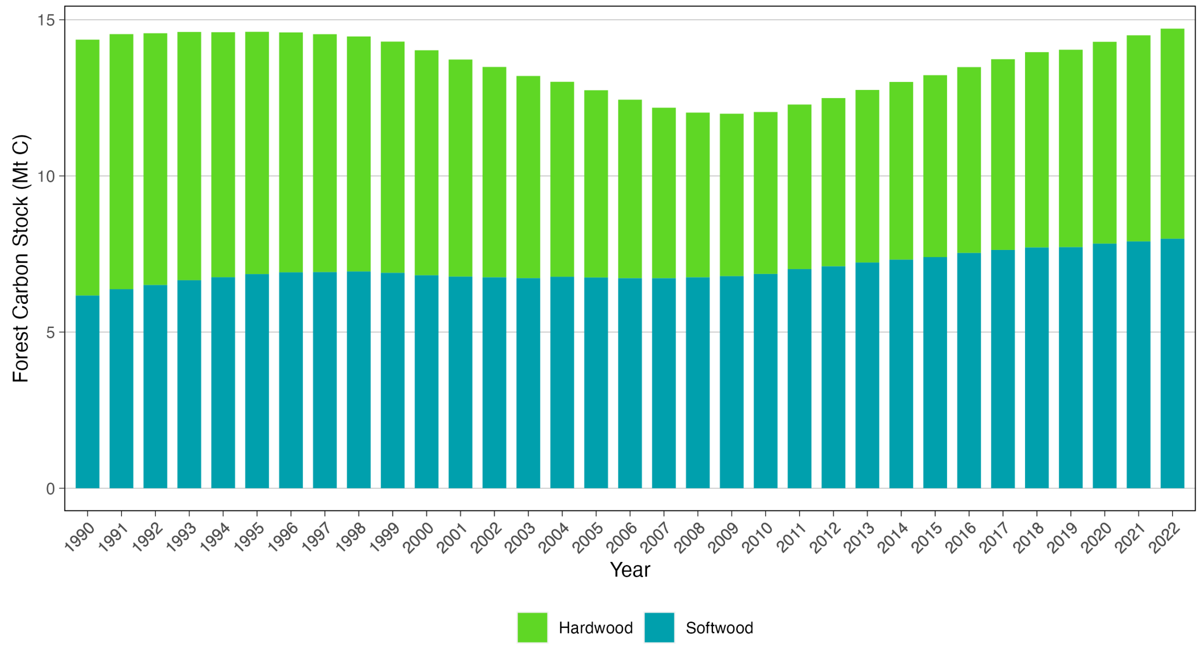

Figure 10 - Estimates of forest carbon stock (including AGB, BGB, DOM and HWP in use) from 1990-2022 in plantations on PTPZL.

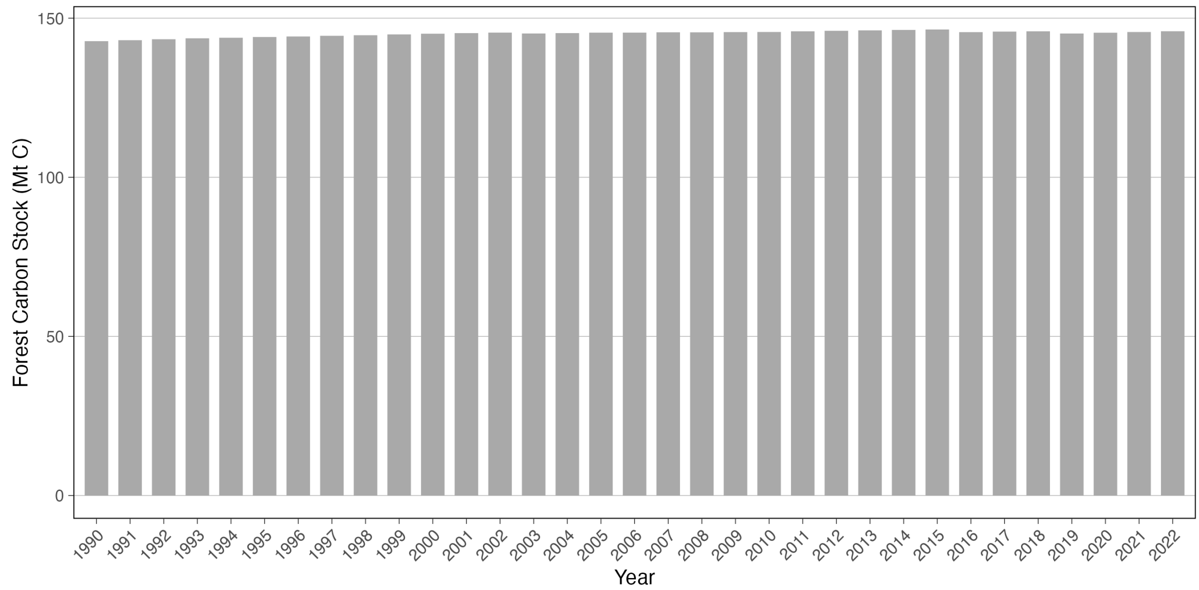

Figure 11 - Estimates of forest carbon stock (including AGB, BGB, DOM and HWP in use) from 1990-2022 in native forests (no plantations) on PTPZL.

The annual changes in carbon stocks are shown in Figure 12. This indicates that there were major losses in carbon in 2003, 2016 and 2019. These were largely due to large wildfires in those years. A map showing the change in carbon stocks between 1990 and 2022 is shown in Figure 13.

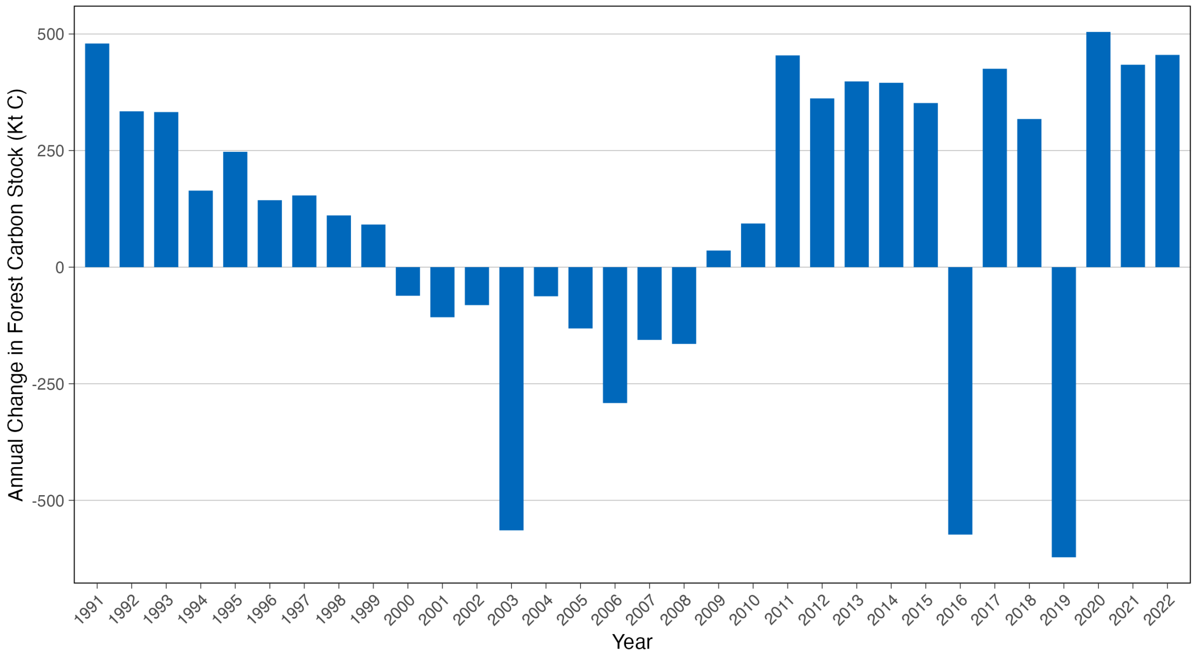

Figure 12 - Net annual change in forest carbon stock across PTPZL from 1991-2022, including AGB, BGB, DOM and HWP in use. Negative numbers indicate a net loss in forest carbon, while positive numbers represent a net gain in forest carbon.

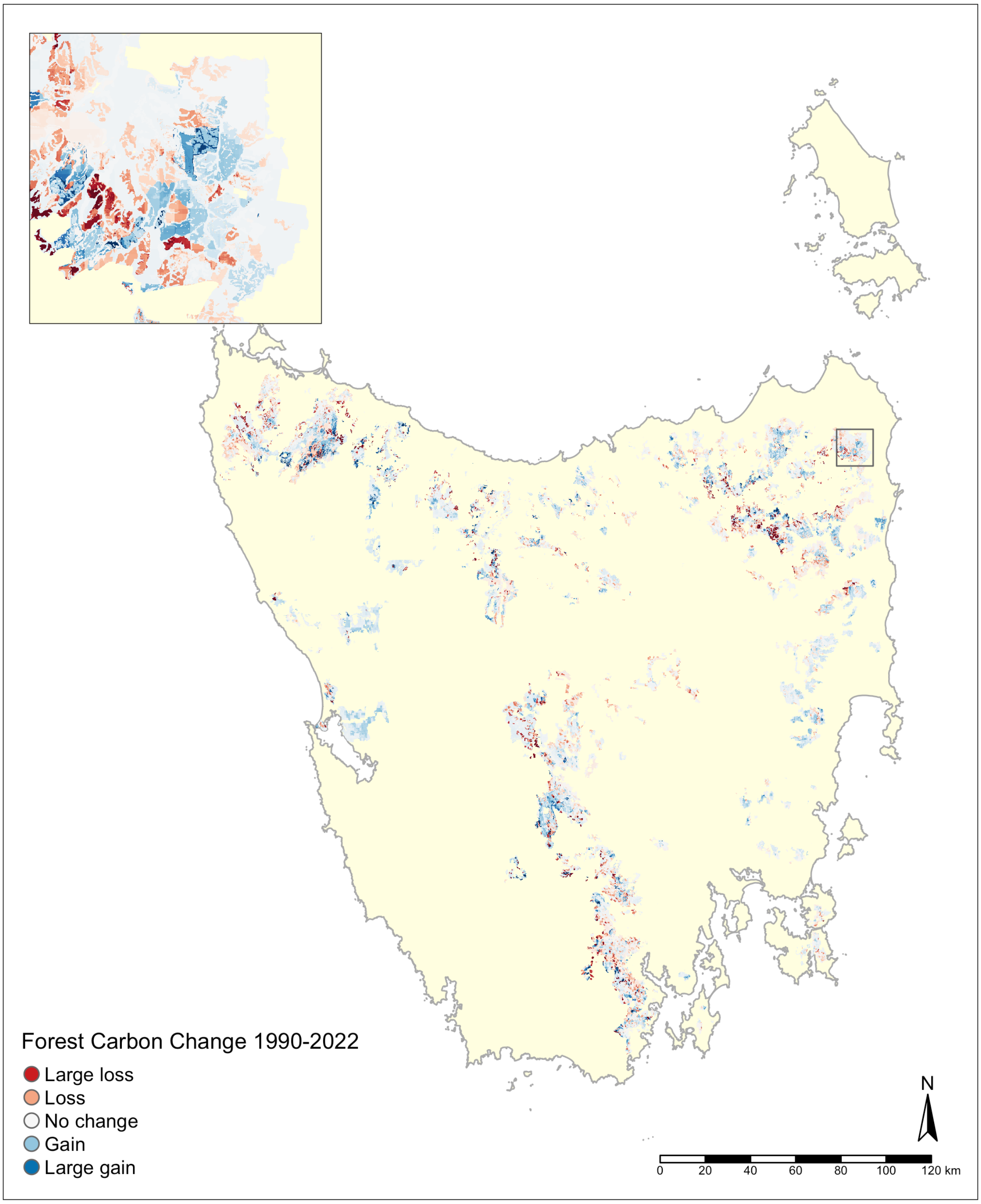

Figure 13 - Spatial output indicating the areas where forest carbon has increased (blue) and decreased (red) across PTPZL between 1990 and 2022. A zoomed in inset map of an area in the northeast is also shown.

Carbon fluxes associated with clearing, harvest, prescribed fire and wildfire events are shown in Figure 14. Note that these are not emissions, but movements of carbon from one pool to another. The data indicates large fluxes due to wildfire in 2003, 2016 and 2019. It also shows harvest events to be generally higher pre 2012 than post. Clearing fluxes here (from the national forest cover data) are only applicable to areas which are currently considered plantation. Clearing in native forests (i.e., no associated harvesting event) were not modelled (as with the national inventory).

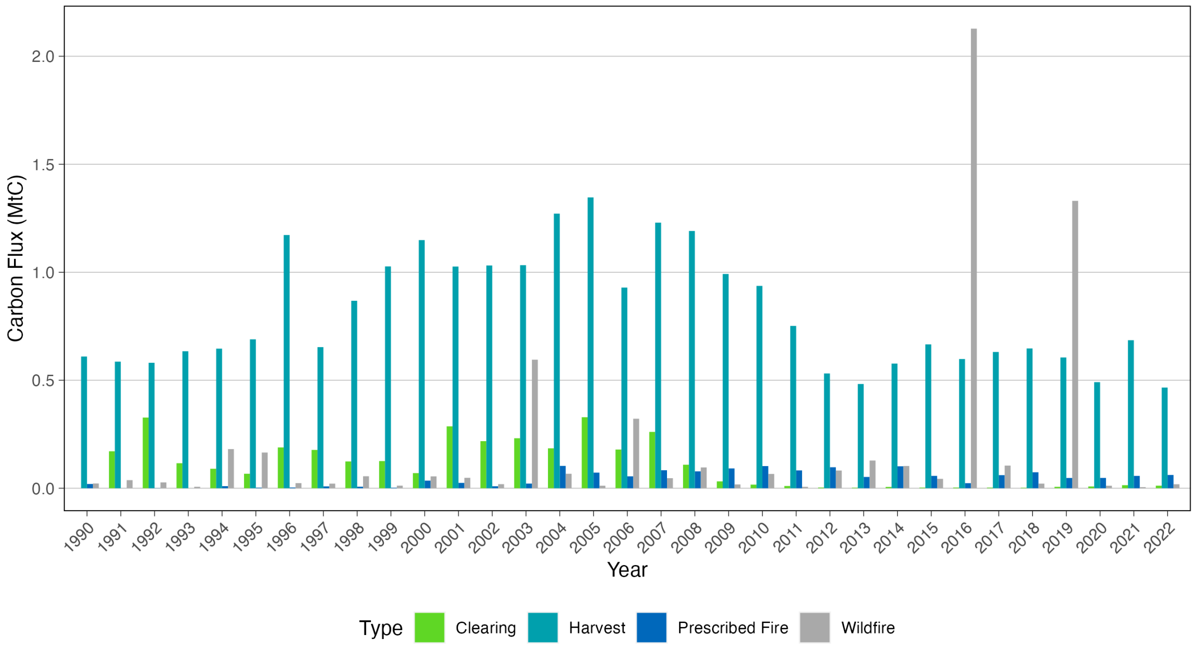

Figure 14 - Carbon fluxes due to clearing, harvest, prescribed fire and wildfire across the STT estate between 1990 and 2022. Note that fluxes are not emissions, they represent movements from one pool to another. Clearing events only represent those in the 2023 plantation extent which were native forest in 1990 and did not have a corresponding harvest record.

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 STT, improved data inputs, especially with respect to harvesting (and replanting) events, would provide better outputs. The FLINTpro team identified issues with the spatial data, both in terms of the spatial alignment of the polygons and the attribution of harvest events through time.

Regarding plantations, especially those that have transitioned from native forest to plantation or from one type to another, data on the timing of these transitions would enable more accurate modelling.

The location and timing of fire events is another area where there are always opportunities for improvements. 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 NGGI and FLINTpro. This layer represents that maximum biomass that all forest areas grow towards. It has been identified that in several areas of Australia, including Tasmania, 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 carbon stock numbers.

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 15.

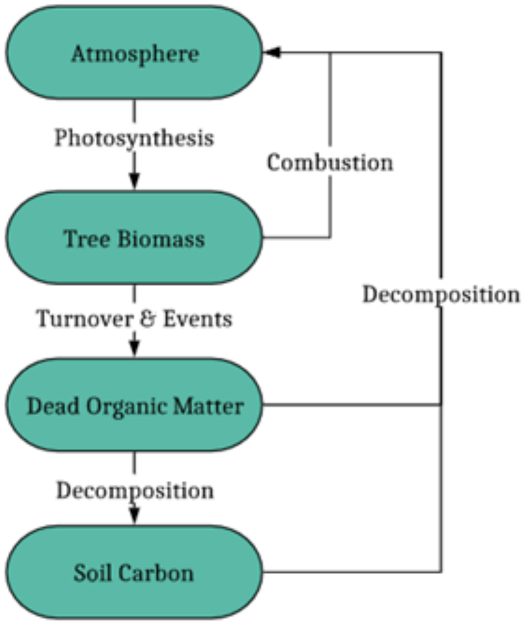

Figure 15 – Simplified example of the natural carbon cycle, with the cyclical movement of carbon from the atmosphere into three terrestrial carbon pools, and back to the atmosphere.

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 5.1). The main types of native forests within the STT estate are open eucalypt forests and woodlands, and rainforests, particularly in the northwest of the state. 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 $\mathrm{MIN}_{r\times M} \leq r \times M \leq \mathrm{MAX}_{r\times M}$, else

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

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

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 ($\mathrm{MIN}_{r\times M}$, $\mathrm{MAX}_{r\times M}$) then $r \times M$ (as calculated above) is used in the TYF. If $r \times M$ is less than $\mathrm{MIN}_{r\times M}$ $\mathrm{MIN}_{r\times M}$ / M is used for r . If $r \times M$ is greater than $\mathrm{MAX}_{r\times M}$ then $\mathrm{MAX}_{r\times M}$ / M is used for r.

The parameters used for plantation growth in this simulation are shown in Table 7

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 6.37 was used for all native forests (i.e., not plantations). Tree growth is also influenced by the FPI, a time-series of spatial data that was provided by STT for use in this project.

Plantation Forests

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). The implementation under this project used growth parameters from the 2020 FullCAM release. Where a plantation species falls within an NPI region but does not have a specific calibration, natural forest calibrations were applied.

Table 7 - 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 16), which is not realistic. This age-related growth adjustment is a characteristic of FullCAM's TYF. It is anticipated that this functionality will change with future updates to FullCAM based on recent work by CSIRO (See Roxburgh et al. 2019)

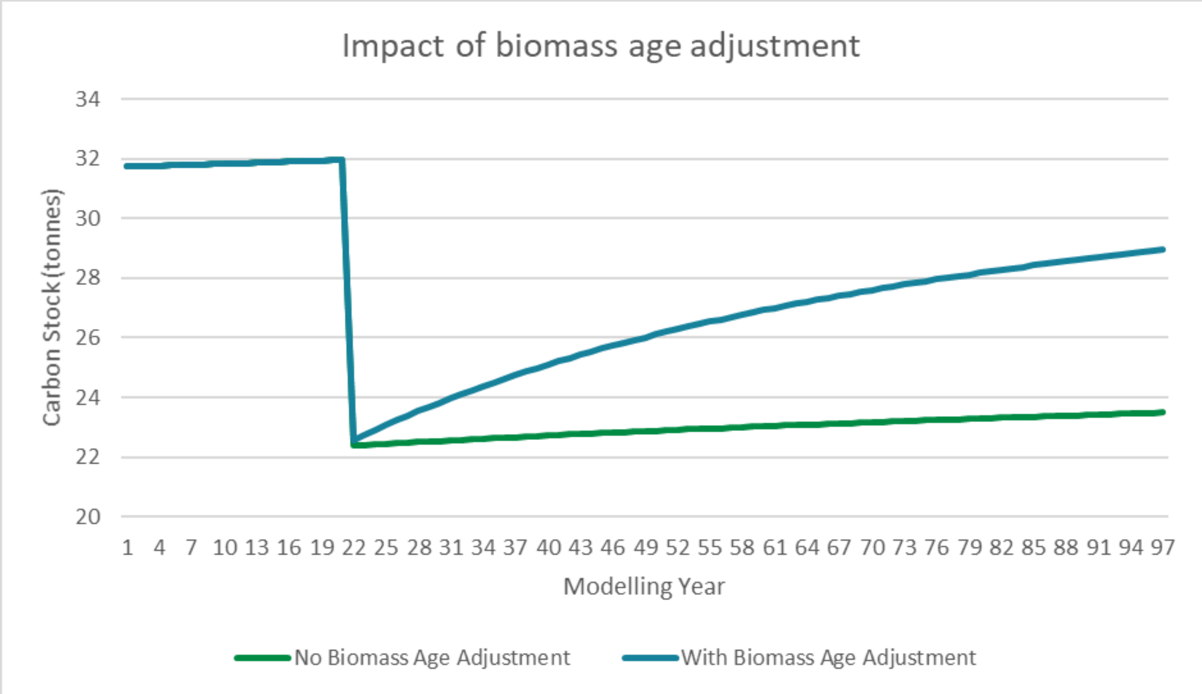

Figure 16 – Demonstration of the impact of biomass age adjustment as modelled in FullCAM and replicated in FLINTpro. Without biomass age adjustment, following a disturbance the forest continues to accumulate carbon at the same rate as prior to the disturbance. With biomass age adjustment turned on, the 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 STT forests, FLINTpro has incorporated 34 carbon pools (Table 8). Non-CO_2 gases, including methane and nitrous oxide, were not included in this analysis. In broad terms, these pools represent the tree biomass, debris biomass, and harvested wood products. Note that soil carbon was 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. 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 8 – 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

Harvested Wood Products

Harvested Wood Products represent a carbon store that is subject to decay. Harvested Wood Products in-use (e.g., construction materials) and in landfill can be modelled through FLINTpro. They were included using methods comparable with the public release of FullCAM, where a proportion of the product pool decays through time (percent per annum) or is burnt as biofuel.

While FLINTpro supports modelling of harvested wood products in landfill, as FullCAM does not include relevant values for the transfer of carbon from products in use to products in landfill, this functionality was not used.

This approach differs from that used in the NGGI which has better accounts for long-term carbon storage of products. Modelling of carbon in harvested wood products in service under the NGGI is not completed with FullCAM, rather a separate database model is used. This model assigns products to pools of varying ages, with simulated periodic losses from each product pool (Richards et al 2007). This approach more faithfully represents the likely behaviour of products in service, compared to the use of generic, simple decay curves. Carbon in harvested wood products moves between respective pools via a range of end-of-life options: recycling, bioenergy, natural decay or landfill. This approach requires the tracking of the age of products in the harvested wood product pools, and the gains and losses from these cohorts.

5.3. Parameters

5.3.1. Harvest parameters

Table 9. Harvesting parameters used in the simulation to transfer carbon across pools

Parameter	CLF	CLTN	HW	SW	PART	AGR	GPS	ARN	CLF	ECF	RLS	DRN	PSR
fraction of basal Area affected	0.95	0.95	1	1	0.7	0.7	0.7	0.75	0.95	0.95	0.95	0.95	0.7
frac_stem_to_deadwood	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
frac_stem_to_biofuel	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_stem_to_paper and pulp	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.7
frac_stem_to_packing_wood	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_stem_to_furniture	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0
frac_stem_to_Fibreboard	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_stem_to_construction	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.13
frac_stem_to_mill_residue	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.08
frac_branch_to_deadwood	1	1	1	1	1	1	1	1	1	1	1	1	1
frac_branch_to_biofuel	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_branch_to_paper_and_pulp	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_branch_to_packing_wood	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_branch_to_furniture	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_branch_to_fiberboard	0	0	0	0	0	0	0	0	0	0	0	0	0

frac_branch_to_construction	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_branch_to_mill_residue	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_bark_to_bark_litter	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
frac_bark_to_biofuel	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_bark_to_paper_and_pulp	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_bark_to_mill_residue	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
frac_leaf_to_leaf_litter	1	1	1	1	1	1	1	1	1	1	1	1	1
frac_leaf_to_biofuel	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_coarse_root_to_dead_coarse_root	1	1	1	1	1	1	1	1	1	1	1	1	1
frac_coarse_root_biofuel	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_fine_root_to_dead_fine_root	1	1	1	1	1	1	1	1	1	1	1	1	1
frac_deadwood_to_biofuel	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_chopped_wood_to_biofuel	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_bark_litter_to_biofuel	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_leaf_litter_to_biofuel	0	0	0	0	0	0	0	0	0	0	0	0	0
Parameter	**PSW**	**SED**	**STX**	**SW1**	**SW2**	**Part**	**OTS**	**CTP1**	**CTP2**	**SKC1**	**CPT2**	**SCWT**	**POST**
fraction of basal Area affected	0.7	0.85	0.95	0.7	0.95	0.7	0.7	0.5	0.5	0.5	0.5	0.5	0.5
frac_stem_to_deadwood	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
frac_stem_to_biofuel	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_stem_to_paper and pulp	0.7	0.45	0.45	0.45	0.45	0.45	0.45	0.7	0.7	0.7	0.7	0.7	0.13
frac_stem_to_packing_wood	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_stem_to_furniture	0	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0	0	0	0
frac_stem_to_Fibreboard	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_stem_to_construction	0.13	0.25	0.25	0.25	0.25	0.25	0.25	0.13	0.13	0.13	0.13	0.13	0.7
frac_stem_to_mill_residue	0.08	0.15	0.15	0.15	0.15	0.15	0.15	0.08	0.08	0.08	0.08	0.08	0.08
frac_branch_to_deadwood	1	1	1	1	1	1	1	1	1	1	1	1	1
frac_branch_to_biofuel	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_branch_to_paper_and_pulp	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_branch_to_packing_wood	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_branch_to_furniture	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_branch_to_fiberboard	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_branch_to_construction	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_branch_to_mill_residue	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_bark_to_bark_litter	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
frac_bark_to_biofuel	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_bark_to_paper_and_pulp	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_bark_to_mill_residue	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
frac_leaf_to_leaf_litter	1	1	1	1	1	1	1	1	1	1	1	1	1
frac_leaf_to_biofuel	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_coarse_root_to_dead_coarse_root	1	1	1	1	1	1	1	1	1	1	1	1	1
frac_coarse_root_biofuel	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_fine_root_to_dead_fine_root	1	1	1	1	1	1	1	1	1	1	1	1	1
frac_deadwood_to_biofuel	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_chopped_wood_to_biofuel	0	0	0	0	0	0	0	0	0	0	0	0	0

frac_bark_litter_to_biofuel	0	0	0	0	0	0	0	0	0	0	0	0	0
frac_leaf_litter_to_biofuel	0	0	0	0	0	0	0	0	0	0	0	0	0

5.3.2. Carbon fractions and breakdown parameters

Table 10 - Carbon Fraction and Turnover Rates for each forest vegetation type

		Carbon Fractions						Turnover Fractions				
id	MVG 5.1	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 11 - 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

id	Resistant fractions						Allocations					
	stem	branch	bark	leaf	coarse root	fine root	stem	branch	bark	leaf	c. root	fine root
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 12 - 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
207	0	0	0	0.0772	0	0.00013	4.5002	4.5002	3.5002	1.1752	3.0003	0.00013

Table 13 - 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

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
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

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