



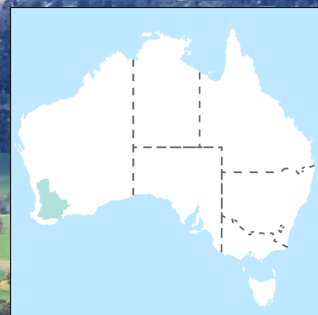
Australia's National
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Methods for developing account-ready data: terrestrial carbon storage, sequestration and emissions in the Western Australian Wheatbelt

Supplementary metadata for a data collection from the
Regional Ecosystem Accounting Pilot projects

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October 2023



Citation

Roxburgh SH, Liu N, Stewart SB, Smith GS, Tetreault-Campbell S and Schmidt RK (2023) Methods for developing account-ready data: terrestrial carbon storage, sequestration and emissions in the Western Australian Wheatbelt. In: Account-ready data: ecosystem services in the Western Australian Wheatbelt. A data collection from the Regional Ecosystem Accounting Pilot projects. CSIRO. Data Collection. <https://data.csiro.au/collection/csiro:59267>

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Acknowledgements

This is an output of the Ecosystem Accounting Pilots for Agricultural and Mixed-Use Landscapes project, one of two Regional Ecosystem Accounting Pilot projects. These are a scientific collaboration between the Department of Climate Change, Energy, the Environment and Water (DCCEEW), CSIRO and others. This project has been funded by DCCEEW under the national strategy for A Common National Approach to Environmental Economic Accounting. For more information see <http://eea.environment.gov.au>.

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Credits

Cover photo: Agricultural landscape in the Western Australian Wheatbelt. showing a tapestry of grain and canola crops, alley farming, roadside trees and remnant vegetation. Source: Suzanne Prober, CSIRO.

Cover map sources: Australian Bureau of Statistics Australian Statistical Geography Standard (ASGS) Edition 3, © Commonwealth of Australia (state boundary); The ecosystem accounting area for these ecosystem accounts is the Western Australian Wheatbelt, as defined by the Climate Services for Agriculture platform.

Contents

Contributors	iv
Acknowledgements.....	vi
1 Introduction	1
1.1 Background	2
1.2 Overall description of the data collection for this accounting component	3
2 Method	4
2.1 Concepts and conceptual models	4
2.2 Data processing.....	6
2.3 Data dictionary.....	21
2.4 Accuracy, assumptions, and limitations	24
Glossary	30
References	35
Suite of technical outputs for <i>Ecosystem Accounting Pilots for Agricultural and Mixed-Use Landscapes</i> project: Western Australian Wheatbelt project.....	39

Figures

Figure 1 This project delivered datasets and a coherent set of accounts for ecosystem extent and condition; biodiversity; and ecosystem services (in physical and monetary terms).....	1
Figure 2 Projects and regions	3
Figure 3 Conceptual diagram of carbon flows in SEEA ecosystem accounting	5
Figure 4 SA2-level FullCAM perennial grass species used in the simulations, as determined by spatial availability and state-level parameter sets within the FullCAM system.....	14
Figure 5 Flowchart for simplifying the unique ecosystem state changes: (a) original (unfiltered) history, with four states present, (b) – (d) The outcome of three successive filters to fill short-duration state persistence's of 1-3 years.....	17
Figure 6 (a) Spatial distribution of the 1356 unique combinations of ecosystem state change history, with each colour representing a unique combination and grey represents grid cells with no state change over the period 1988-2020, comprising ~66% of the total area; (b) Spatial distribution of the 10,896 unique combinations of ecosystem state change history and fire history, with each colour representing a unique combination	19
Figure 7 Summary flow chart of the overall analysis for the non-agricultural land cover classes, combining FullCAM model emulation (for cases where there are > 100 pixels represented across the MDB per unique combination of land cover and fire history) with direct runs of the FullCAM model, for those cases with insufficient data to support emulation model development and testing (≤ 100 pixels represented across the MDB per unique combination of land cover class and fire history).....	19
Figure 8 Example FullCAM output results for three of the 10,896 unique combinations of ecosystem state change and fire history depicting (a) Eucalyptus Open Forest in a reference state, (b) Crop with a transition in 2009 to a Mixed Species Environmental Planting, (c) Modified mallee with a transition to cropping in 2009	20
Figure 9 Example FullCAM predictions (x-axis, 'Obs') and emulation model predictions (y-axis, 'Pred') for a single unique land cover change x fire history combination.....	27

Tables

Table 1 Crosswalk between ecosystem types and states defined across the WAW catchments by Khan et al. (2023), and vegetation classes used for FullCAM modelling.....	9
Table 2 Ecosystem state transitions detected across the WAW domain for the period 1988-2020, and the FullCAM approach to representing those transitions.....	16
Table 3 List of FullCAM output variables saved	18
Table 4 List of derived variables for reporting, and their calculation based on the quantities in Table 2.....	18
Table 5 Final set of 11 variables used for reporting, and the file names for the associated mapped products	18
Table 6 Validation statistics for spatial FullCAM emulation across the Western Australian Wheatbelt	26

Contributors

The Regional Ecosystem Accounting Pilot projects, under the Strategy and Action Plan for a Common National Approach to Environmental Economic Accounting, included two projects:

- Project 1: Ecosystem Accounting Pilots for Agricultural and Mixed-Use Landscapes
- Project 2: Ecosystem Accounts for the Murray-Darling Basin.

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Acknowledgements

This is an output of the *Ecosystem Accounting Pilots for Agricultural and Mixed-use Landscapes* project, one of two Regional Ecosystem Accounting Pilot projects. These are a scientific collaboration between the Department of Climate Change, Energy, the Environment and Water (DCCEEW), CSIRO and others. This project has been funded by DCCEEW under the *Strategy and Action Plan for a Common National Approach to Environmental Economic Accounting*. For more information see <http://eea.environment.gov.au>.

CSIRO and DCCEEW acknowledge the Traditional Owners of country throughout Australia and recognise their continuing connection to land, waters and culture. We pay our respects to their Elders past and present. View CSIRO's *vision towards reconciliation* and DCCEEW's *Reconciliation Action Plan*.

We gratefully acknowledge the input provided by participants at the 'Developing state and transition models to support ecosystem accounting of agricultural and mixed-use landscapes in the Western Australian Wheatbelt' workshop from 19 to 20 September 2022 (and subsequent online condition workshop on 24 November 2022). We also thank them for additional input through online surveys of ecosystem condition for ecosystem states. The information provided at these workshops and surveys has been synthesised in this document. Experts who generously provided their time and feedback include: Brett Beecham, Dimity Boggs, Margaret Byrne, David Collard, Chris Curnow, Christophe D'Abbadie, Bonny Dunlop-Heague, Greg Durell, Paul Galloway, Carl Gosper, Mike Griffiths, Alex Hams, Peta Kelsey, Sarah Luxton, Nathan McQuoid, Helena Mills, Owen Nevin, Tim Overheu, Tina Parkhurst, Blair Parsons, Keith Pekin, Tom Picton-Warlow, Clinton Rakich, Debbi Slater-Lee, Melanie Strawbridge, Grant Wardell-Johnson and Renee Young.

The elicitation of expert knowledge of ecosystem states and transitions, and engagement with First Nations peoples in this study, was approved by CSIRO's Social Science Human Research Ethics Committee in accordance with the National Statement on Ethical Conduct in Human Research (2007): ethics approval 115/22.

The elicitation of expert knowledge of ecosystem condition in this study was approved by CSIRO's Social Science Human Research Ethics Committee (CSHREC) in accordance with the National Statement on Ethical Conduct in Human Research (2007): ethics clearance 115/22 and 196/23 (the latter covers reuse of data previously collected with ethics clearance: 004/17, 025/18, 204/19).

We gratefully acknowledge Chiara Pasut for peer review comments on an earlier version of this methods statement which improved this final version.

1 Introduction

This document provides supplementary metadata for the following data collection in the CSIRO Data Access Portal (DAP):

Smith GS, Evans D, Liu N, Roxburgh SH, Stewart SB, Tetreault-Campbell S and Schmidt RK (2023) Account-ready data: ecosystem services in the Western Australian Wheatbelt. A data collection from the Regional Ecosystem Accounting Pilot projects. CSIRO. Data Collection. <https://data.csiro.au/collection/csiro:59267>

This DAP entry includes the full metadata and data collection (including account-ready data), for all ecosystem services for the Western Australian Wheatbelt (Figure 1).

This methods statement covers a part of this set of account-ready data: the terrestrial carbon storage, sequestration and emissions account-ready data.

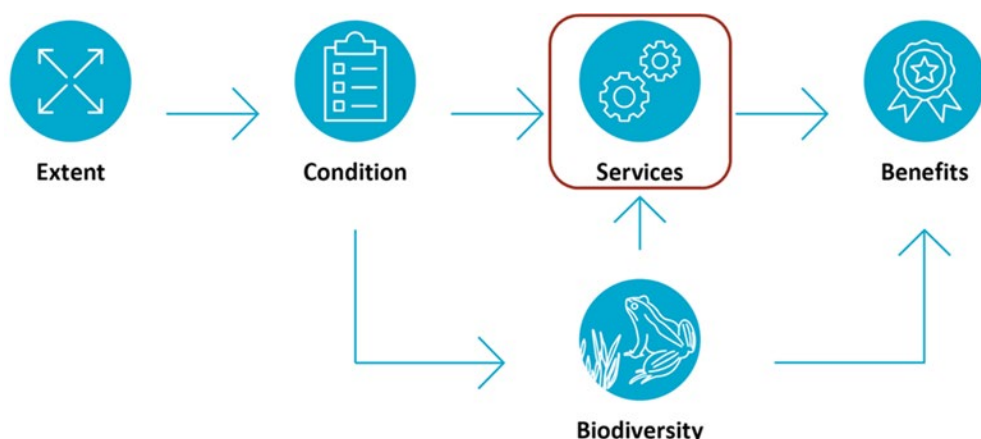


Figure 1 This project delivered datasets and a coherent set of accounts for ecosystem extent and condition; biodiversity; and ecosystem services (in physical and monetary terms).

For the Western Australian Wheatbelt, this project also delivered conceptual models to underpin ecologically-meaningful interpretation of the accounts.

The red box encloses the accounting components described in this method statement.

This account-ready data was used to develop experimental ecosystem accounts for terrestrial carbon storage, sequestration and emissions (Figure 1). A corresponding data collection provides all experimental ecosystem accounts for the Western Australian Wheatbelt ([Richards et al. 2023](#))¹.

The experimental ecosystem accounts for terrestrial carbon storage, sequestration and emissions comprise 3 Excel workbooks (Smith et al. 2023b, 2023c, 2023d), which can be found in a subfolder of that name in [Richards et al. \(2023\)](#). Also provided are supplementary data tables, maps and charts, and methods for compiling accounts (Liu et al. 2023).

¹ Data collections for the Regional Ecosystem Accounting Pilot projects are hyperlinked in dark teal.

1.1 Background

The Strategy and Action Plan for a Common National Approach to Environmental Economic Accounting advocates an approach to account development that is driven by policy and decision-making needs.

The Regional Ecosystem Accounting Pilot (REAP) projects (the ‘projects’) delivered ecosystem accounts at sub-national scale that:

- demonstrate value for policy and decision making, engage key stakeholders and increase demand for an ongoing program of ecosystem accounts
- contribute towards the longer-term goal of national ecosystem accounts by testing methods that can be scaled nationally and by increasing capacity for ecosystem accounting in Commonwealth institutions.

The projects were informed by experience gained in delivery of the National Land Account and pilot ecosystem accounts for Geopraphe Marine Park and Gunbower-Koondrook-Perricoota (links to CSIRO-led outputs are at <https://www.csiro.au/en/research/natural-environment/natural-resources/Natural-capital-accounting/Murray-Darling>).

The projects applied the United Nations (UN) System of Environmental-Economic Accounting (SEEA) and UN System of National Accounts (SNA) frameworks and standards where relevant. However, in some cases, the Projects departed from, or extended, the frameworks.

Two projects were undertaken (Figure 2):

- Project 1: Ecosystem Accounting Pilots for Agricultural and Mixed-Use Landscapes
- Project 2: Ecosystem Accounts for the Murray-Darling Basin.

This document covers account-ready data delivered as part of project 1, for the Western Australian Wheatbelt. It includes:

- an overall description of the data collection (Section 1.2)
- methods for developing account-ready data
 - concepts and conceptual models (Section 2.1)
 - the data processing steps applied for developing account-ready data (Section 2.2)
- the results from applying the methods
 - a list of the data products that are part of this collection (Section 2.3)
 - accuracy, assumptions and limitations (Section 2.4).

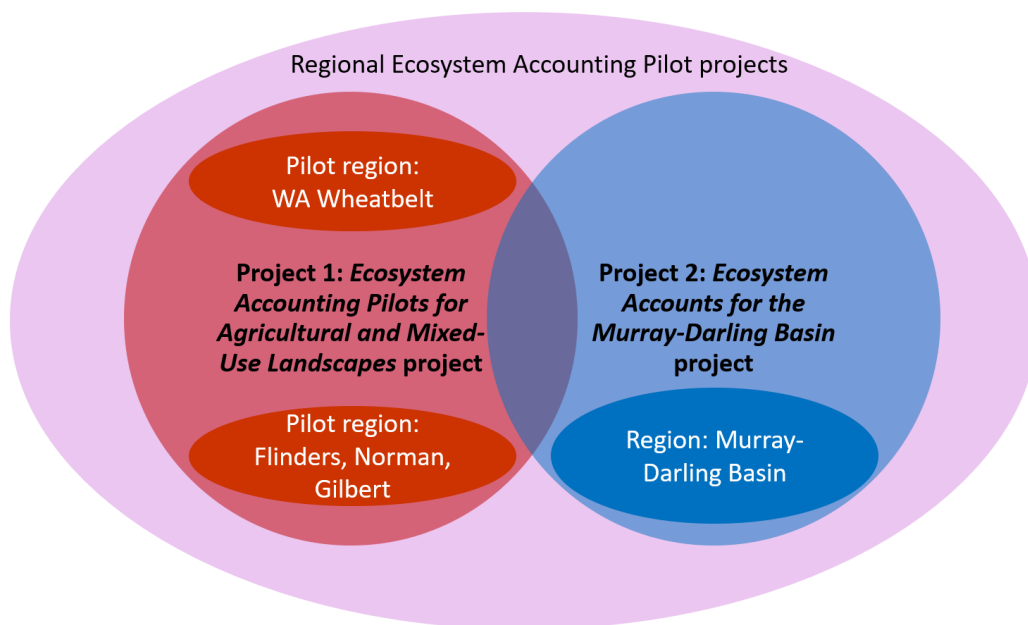


Figure 2 Projects and regions

1.2 Overall description of the data collection for this accounting component

This methods statement is one of several supporting files that provide supplementary metadata for the data collection of account-ready data for all ecosystem services assessed in the Western Australian Wheatbelt (Smith et al. 2023a). The ‘collection description’ for the whole data collection is as follows:

This collection comprises account-ready data for the Western Australian Wheatbelt for the following ecosystem services: (1) terrestrial carbon storage, sequestration and emissions and (2) biomass provisioning. Supplementary socio-economic data are also provided. It includes annual time-series provided as spatial data (.GPKG and .TIFF) and Excel spreadsheets.

Subfolders are provided in the data collection, for each ecosystem service and the supplementary socio-economic data.

This methods statement covers terrestrial carbon storage, sequestration and emissions, described as follows:

Terrestrial carbon storage, sequestration and emissions: Spatial emulation of the Full Carbon Accounting Model (FullCAM) is used to develop an annual time-series (1988-2020) of terrestrial carbon storage, sequestration, and emissions across the Western Australian Wheatbelt (WAW) at a spatial resolution of 100 m. Both stocks (carbon mass of crops, pastures, forests, woodlands, shrublands, debris and soil) and fluxes (emissions of CO₂, N₂O and CH₄ due to fire, heterotrophic respiration, net primary productivity, net ecosystem carbon balance) of carbon are provided in units of tCO₂e ha⁻¹ and tCO₂e ha⁻¹ yr⁻¹, respectively. Emission factors and other quantities used to convert CH₄ and N₂O fire emissions to CO₂e are provided in Section 6.4.5.1 of DISER (2022) (<https://www.dcceew.gov.au/sites/default/files/documents/national-inventory-report-2020-volume-2.pdf>).

2 Method

2.1 Concepts and conceptual models

The SEEA EA standard (United Nations et al. 2021) provides a framework for ecosystem accounting. Following the conceptual approach of the SEEA EA, humans are assumed to derive benefits from ecosystems through their use of those ecosystem services. Some ecosystem services contribute to benefits that are delivered as goods and services within the economy (e.g. food, timber, water etc.). These benefits are already included within the System of National Accounts (SNA) (United Nations Statistics Division 2008); these benefits are termed ‘SNA benefits’ and already form part of measures such as gross domestic product (GDP). Other ecosystem services contribute to benefits that are not within the production boundary of the SNA (e.g. clean air, flood protection or water filtration provided by ecosystems). These benefits are termed ‘non-SNA benefits’ (United Nations et al. 2021; section 6.2.2, p.123). The SEEA EA aims to account for the ecosystem contribution to both SNA benefits and non-SNA benefits.

Ecosystem services can therefore be defined as the contributions of ecosystems to the benefits that are used in economic and other human activity (United Nations et al. 2021; section 6.2.1 p.121).

2.1.1 Carbon stocks

For the purposes of carbon accounting in the SEEA EA framework (United Nations et al. 2021), carbon stocks broadly include:

- geocarbon (carbon stored in the geosphere)
- biocarbon (carbon stored in the biosphere, in living and dead biomass, and soil organic carbon)
- carbon in the oceans (carbon dissolved in seawater, noting carbon in sediments is part of biocarbon or geocarbon)
- carbon in the atmosphere
- carbon accumulated in the economy.

The component of the carbon cycle of interest to ecosystem accounting is carbon in the biosphere (e.g. carbon in soil, in above- and below-ground biomass, and in dead biomass). Thus, in this project ‘carbon stocks’ refer to the carbon mass of crops, pastures, forests, woodlands, shrublands, debris and soil. Carbon stocks associated with the atmosphere, oceans and geocarbon were out of scope for this project.

2.1.2 Services related to carbon

Figure 3 shows a conceptual diagram of services related to carbon that are considered in this project. Elements are defined as follows:

- **Carbon stocks** are the mass of carbon stored in living biomass, dead biomass, and the soil.
- **Carbon fluxes** are the rates at which carbon is passed between the different carbon stocks (such as the rate of litterfall in forests, and the transfer of dead organic matter to soil organic carbon),

and the rates at which carbon is passed between the biosphere and the atmosphere (such as net primary productivity (NPP), the decomposition of organic matter, and emissions from biomass burning).

- **Carbon sequestration** is the net rate at which carbon is removed from the atmosphere, contributing to climate regulation (it is crucial that this capture is long term). Carbon sequestration is defined here as the Net Ecosystem Carbon Balance (Section 2.3.1).
- **Emissions** are ‘releases of gases to the atmosphere (e.g., the release of carbon dioxide during fuel combustion). Emissions can be either intended or unintended releases.’
(https://unfccc.int/resource/cd_roms/na1/ghg_inventories/english/8_glossary/Glossary.htm)
- **CO₂-e** is the mass of carbon and non-CO₂ greenhouse gasses converted to units of carbon dioxide equivalents, through application of the emission factors provided in Section 6.4.5.1 of DISER (2022). Conversion to CO₂-e allows different greenhouse gasses to be compared in the same units, accounting for their different global warming potentials.

Carbon stocks are reported in either units of mass per unit area (e.g. tCO₂-e ha⁻¹) or when reporting the total stock summed over a spatial domain, as an absolute amount (e.g. MtCO₂-e). Carbon fluxes are reported in either units of mass per unit area per unit time (e.g. tCO₂-e ha⁻¹ yr⁻¹), or mass per unit time when summed over a spatial domain (e.g. MtCO₂-e yr⁻¹).

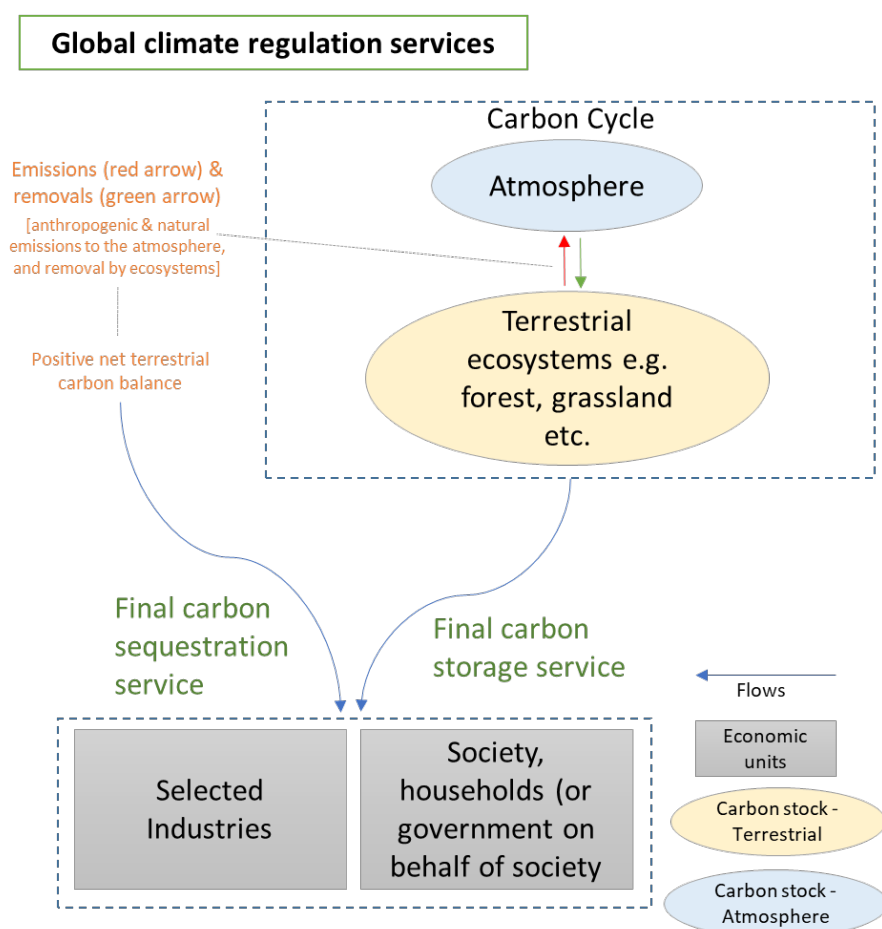


Figure 3 Conceptual diagram of carbon flows in SEEA ecosystem accounting

Broadly, services related to carbon fall under global climate regulation services, defined as:

Global climate regulation services are the ecosystem contributions to reducing concentrations of GHG in the atmosphere through the removal (sequestration) of carbon from the atmosphere and the retention (storage) of carbon in ecosystems. These services support the regulation of the chemical composition of the atmosphere and oceans. This is a final ecosystem service. (United Nations et al. 2021; Table 6.3, p.132).

2.2 Data processing

The Full carbon Accounting Model (FullCAM²) is a freely available software system for tracking greenhouse gas emissions and changes in carbon stocks associated with land use and management in Australian agricultural and forest systems (Richards and Brack 2004; Waterworth et al. 2007; Waterworth and Richards 2008). It is applied at the national scale for land sector emissions accounting, and at the local scale for monitoring and reporting carbon sequestration projects under the emissions reduction fund, such as revegetation and the management of regrowth.

As a full-system carbon balance model FullCAM provides estimates of carbon stocks and fluxes at either daily, weekly, monthly or annual temporal resolutions, with a monthly time step used in the simulations described below. However, because the public version of the software can only be run at a single point location, extensive spatial applications require additional software development (such as in R, Python or other programming platforms) to interact with the FullCAM software, to allow spatial analysis to be performed, and for results to be saved in a GIS format suitable for reporting. A significant advantage of using FullCAM for accounting is that the methods are consistent with those used for Australia's national greenhouse gas reporting to the international community, under the United Nations Framework Convention on Climate Change (UNFCCC).

Within FullCAM all the information for running a simulation at a location (defined by a single latitude and a longitude) is contained within a 'plotfile'. Running the FullCAM model spatially therefore requires updating a plotfile for each pixel location through a call to the FullCAM server. This update copies the new location-specific climate data and spatially varying parameters such as *M* (the maximum above-ground biomass for any location) and the Forest Productivity Index (*FPI*) into the plotfile. That plotfile is then processed and the required results saved for further analysis, before moving to the next location, and repeating the process. This is computationally time-consuming. For example, prior testing suggested an analysis of the WAW catchment at a 100 m resolution (>12 million pixels) would not be feasible to undertake, with experiments suggesting several weeks of processing time to complete, and with the likelihood of being denied access through excessive data requests to the FullCAM server.

This limitation can be overcome for the simulation of both agricultural and woody vegetation. For woody vegetation and soil organic carbon, the FullCAM model can be readily emulated (Heuvelink et al. 2021; Luo et al. 2013) using simple linear functions that relate a given FullCAM output to three key spatially varying parameters: *M* (the maximum attainable above-ground biomass achievable at a location), *FPI* (a dimensionless forest productivity index) and the initial soil carbon stock (*SOC_i*) (used for predicting changes in soil organic carbon). In this way a relatively small

² The latest version of FullCAM can be downloaded from <https://www.dcccew.gov.au/climate-change/publications/full-carbon-accounting-model-fullcam>

number of calls to the FullCAM server can be used to develop the relationships between each output variable to the input parameters, and then those relationships can be applied spatially using the input parameter layers, which are available as downloadable GIS maps.³ A separate emulation model is required for each combination of required output variable, each date to be saved (year and month), and unique disturbance and land cover history (for this analysis, the land cover history was based on the time series of ecosystem state changes derived by Khan et al. (2023) specifically for this project). Data pre-processing is therefore required to determine all of the unique disturbance and land cover history combinations that are present across the spatial analysis domain, described below under *generating plotfiles*.

Emulation models for all woody living biomass ($C_Biomass_{ijk}$), woody debris (C_Debris_{ijk}) and fire emissions ($Emissions_{ijk}$), for a given output variable i , save date j and unique land cover history class k were of the form:

$$C_Biomass_{ijk} = x_0 + x_1 FPI + x_2 M$$

$$C_Debris_{ijk} = x_0 + x_1 FPI + x_2 M$$

$$Emissions_{ijk} = x_0 + x_1 FPI + x_2 M$$

In order to obtain satisfactory predictions, emulation models for the soil organic carbon pool required adding the initial soil carbon stock (SOC_i) input parameter, and the initial clay content (fraction, C) of the soil:

$$C_Soil_{ijk} = x_0 + x_1 FPI + x_2 M + x_3 C + x_4 \sqrt{SOC_i}$$

The square-root transformation for SOC_i was found to be necessary to prevent biased predictions in areas of low soil carbon content.

Within FullCAM, growth and turnover for the non-soil components of agricultural vegetation are handled differently to that for woody vegetation, with Statistical Area Level 2 (SA2)-specific growth-parameters providing spatial variability between SA2 regions, but with homogenous growth within SA2 regions. Computational efficiencies for predicting agricultural production can therefore be gained through simulating the agricultural species once for each combination of SA2 region and unique disturbance and land cover history combination, and saving predictions in an SA2-specific 'look-up' table that can then be drawn upon when generating the final pixel-by-pixel mapped results; that is, at the same time as application of the woody vegetation and SOC emulation models.

Making use of emulation (for woody vegetation) and pre-processing (for agricultural vegetation) allowed the analysis to be completed in less than one day using CSIRO's high performance computing facility, based on a sample size of 50 randomly selected locations for fitting each woody vegetation emulation model. In addition to selecting the 50 random locations for model fitting, an additional 50 locations were also selected to independently validate the emulation model

³ Maps of M and FPI can be obtained from <https://data.gov.au/dataset/ds-dga-b46c29a4-cc80-4bde-b538-51013dea4dcb/distribution/dist-dga-1e3af98e-967a-4908-882f-2d217b0d0e5a/details?q=erf>. The SOC_i map can be obtained from https://data.csiro.au/collection/csiro:11467?q=soil%20carbon&_st=keyword&_str=27&_si=2

predictions. Emulation model fit was quantified, using the validation locations, using four statistics: root mean-squared error (RMSE), Bias, Nash-Sutcliffe model efficiency (Nash and Sutcliffe 1970), and Lin's concordance (Lin 2000). The latter two indices both have a value of 1.0 when the FullCAM and emulation predictions are identical.

The steps for preparing FullCAM events and generating plotfiles are described in detail below.

Step A. Crosswalk between ecosystem types and FullCAM classes

To align the range of ecosystem types (and their different state representations) identified by Khan et al. (2023) with species growth parameter calibration sets within FullCAM, the full list of ecosystem types was re-classified (and simplified) using eight woody species types (*Eucalyptus Open Woodland*, *Eucalyptus Open Forest*, *Acacia Forest and Woodland*, *Mallee Woodland and Shrubland*, *Mixed Species Environmental Planting*, *Other Shrubland*, *Melaleuca Forest and Woodland*, and *Casuarina Forest and Woodlands*) (Table 1), and two SA2-specific perennial grass species types (Figure 4). For perennial grass, the available FullCAM species growth parameter sets vary across the continent, with not all species available within all SA2 regions. The map of the FullCAM perennial grass species simulated in each SA2 region (Figure 4) includes 'Perennial grass', and 'Tropical grass'. For cropping lands, the FullCAM *Wheat* growth parameter calibration was used.

Changes in forest biomass potential, for example to reflect a degraded state, were simulated through modifications to the default FullCAM '*r*' parameter growth multiplier. For example, for the "*MalleeModified*" ecosystem type, *r* was set to 0.75 (meaning only 75% of the maximum possible woody biomass can be attained for that location).

A number of aquatic cover classes were not able to be simulated by FullCAM (Table 1). When developing the transition histories, any pixel that was recorded as belonging to one of these classes, in at least one year over the historical record, was flagged as being aquatic, and excluded from analysis.

Table 1 Crosswalk between ecosystem types and states defined across the WAW catchments by Khan et al. (2023), and vegetation classes used for FullCAM modelling

The ecosystem type is identified in blue text, with the ecosystem state description in green text.

ECOSYSTEM TYPE AND STATE	SHORT NAME (KHAN ET AL. 2023)	FULLCAM SPECIES GROWTH PARAMETER SET	FULLCAM PLOTFILE CODE
<p>Mesic heathy mallee: transformed</p> <p>Obligate-seeder eucalypt woodlands: transformed</p> <p>Lowland resprouter temperate and subtropical shrub-grass eucalypt woodlands: transformed</p> <p>Temperate eucalypt woodlands with a heathy understorey: transformed</p> <p>Resprouter eucalypt forests: transformed</p> <p>Sandplain shrublands: transformed</p>	<p>MalleeTransformed, ObSeederTransformed, ShrubGrassTransformed, HeathyTransformed, ForestTransformed, SandplainTransformed.</p>	<p>Eucalyptus Open Woodland (all vegetation cleared in 1950)</p>	<p>Transformed</p>
<p>Mesic heathy mallee: pasture only</p> <p>Mesic heathy mallee: mixed farming</p> <p>Mesic heathy mallee: unmanaged fallow / treeless old field</p> <p>Mesic heathy mallee: other</p> <p>Obligate-seeder eucalypt woodlands: pasture only</p> <p>Obligate-seeder eucalypt woodlands: mixed farming</p> <p>Obligate-seeder eucalypt woodlands: unmanaged fallow / treeless old field</p> <p>Obligate-seeder eucalypt woodlands: other</p> <p>Lowland resprouter temperate and subtropical shrub-grass eucalypt woodlands: pasture only</p> <p>Lowland resprouter temperate and subtropical shrub-grass eucalypt woodlands: mixed farming</p> <p>Lowland resprouter temperate and subtropical shrub-grass eucalypt woodlands: unmanaged fallow / treeless old field</p> <p>Lowland resprouter temperate and subtropical shrub-grass eucalypt woodlands: other</p> <p>Temperate eucalypt woodlands with a heathy understorey: pasture only</p>	<p>MalleePasture, MalleeMixed, MalleeFallow, MalleeOther, ObSeederPasture, ObSeederMixed, ObSeederFallow, ObSeederOther, ShrubGrassPasture, ShrubGrassMixed, ShrubGrassFallow, ShrubGrassOther, HeathyPasture, HeathyMixed, HeathyFallow, HeathyOther, ForestPasture, ForestFallow, ForestOther,, SandplainPasture, SandplainMixed, SandplainFallow, Other</p>	<p>Perennial grass</p>	<p>Pasture</p>

ECOSYSTEM TYPE AND STATE	SHORT NAME (KHAN ET AL. 2023)	FULLCAM SPECIES GROWTH PARAMETER SET	FULLCAM PLOTFILE CODE
Temperate eucalypt woodlands with a heathy understorey: mixed farming Temperate eucalypt woodlands with a heathy understorey: unmanaged fallow / treeless old field Temperate eucalypt woodlands with a heathy understorey: other Resprouter eucalypt forests: pasture only Resprouter eucalypt forests: treeless old fields / abandoned pastures Resprouter eucalypt forests: other Sandplain shrublands: pasture only Sandplain shrublands: mixed farming Sandplain shrublands: unmanaged fallow / treeless old field Other terrestrial vegetation			
Mesic heathy mallee: reference	MalleeReference.	Mallee Woodland and Shrubland	Mallee
Mesic heathy mallee: modified mallee woodlands, with a combination of 2 variants: 'mallee disturbed with moderate ground layer native species richness' and 'mallee disturbed with low ground layer native species richness / high abundance of exotics' Mesic heathy mallee: combination of 'secondary salinised state' and 'rehabilitated salinised land'	MalleeModified, MalleeSalinised.	Mallee Woodland and Shrubland (FullCAM <i>r</i> parameter set to 0.75)	MalleeMod
Mesic heathy mallee: cropping only Obligate-seeder eucalypt woodlands: cropping only Lowland resprouter temperate and subtropical shrub-grass eucalypt woodlands: cropping only Temperate eucalypt woodlands with a heathy understorey: cropping only Sandplain shrublands: cropping only	MalleeCrop, ObSeederCrop, ShrubGrassCrop, HeathyCrop, SandplainCrop.	Wheat	Crop
Resprouter eucalypt forests: reference	ForestReference.	Eucalyptus Open Forest	EucForest

ECOSYSTEM TYPE AND STATE	SHORT NAME (KHAN ET AL. 2023)	FULLCAM SPECIES GROWTH PARAMETER SET	FULLCAM PLOTFILE CODE
Resprouter eucalypt forests: logged	ForestLogged.	Eucalyptus Open Forest (FullCAM <i>r</i> parameter set to 0.75, to reflect reduction in estate-wide carbon storage due to historical logging)	EucForestLogged
<p>Mesic heathy mallee: woody revegetation</p> <p>Obligate-seeder eucalypt woodlands: woody revegetation</p> <p>Lowland resprouter temperate and subtropical shrub-grass eucalypt woodlands: woody revegetation</p> <p>Temperate eucalypt woodlands with a heathy understorey: woody revegetation</p> <p>Resprouter eucalypt forests: mined and regenerating</p> <p>Resprouter eucalypt forests: woody revegetation and plantations</p> <p>Sandplain shrublands: shrubland revegetation</p>	MalleeRevegetation, ObSeederRevegetation, ShrubGrassRevegetation, HeathyRevegetation, ForestMined, ForestRevegetation, SandplainRevegetation.	Mixed Species Environmental Planting	Reveg
<p>Sandplain shrublands: combination of 'reference' and 'shrubland with reduced fire'</p> <p>Sandplain shrublands: other</p> <p>Granite outcrops: reference</p> <p>Granite outcrops: moderately degraded granite outcrops</p> <p>Granite outcrops: with altered water flows</p>	SandplainReference, SandplainOther, GraniteReference, GraniteDegraded, GraniteWaterFlows.	Other Shrublands	Shrublands
Sandplain shrublands: modified shrubland	SandplainModified.	Other Shrublands (FullCAM <i>r</i> parameter set to 0.25)	ShrublandMod
<p>Obligate-seeder eucalypt woodlands: combination of 'reference' and 'modified: low recruitment'</p> <p>Lowland resprouter temperate and subtropical shrub-grass eucalypt woodlands: combination of 'reference' and 'modified: she-oak'</p> <p>Temperate eucalypt woodlands with a heathy understorey: reference</p>	ObSeederReference, ShrubGrassReference, HeathyReference.	Eucalyptus Open Woodland	Woodland
Obligate-seeder eucalypt woodlands: combination of 'secondary salinised state' and 'rehabilitated salinised land'	ObSeederSalinised, ObSeederHighCover, ObSeederSparseCover, ShrubGrassSalinised	Eucalyptus Open Woodland (FullCAM <i>r</i> parameter set to 0.75)	WoodlandMod

ECOSYSTEM TYPE AND STATE	SHORT NAME (KHAN ET AL. 2023)	FULLCAM SPECIES GROWTH PARAMETER SET	FULLCAM PLOTFILE CODE
<p>Lowland resprouter temperate and subtropical shrub-grass eucalypt woodlands: unimproved pasture/modified woodlands, with a combination of 4 variants: 'high tree cover, moderate native plant diversity, moderate exotics', 'high tree cover, low native plant diversity, high exotics', 'thinned trees, moderate native plant diversity, moderate exotics', 'thinned trees, low native plant diversity, high exotics'</p> <p>Lowland resprouter temperate and subtropical shrub-grass eucalypt woodlands: unimproved pasture / modified woodlands, with a combination of 2 variants: 'sparse trees, moderate native plant diversity, moderate exotics' and 'sparse trees, low native plant diversity, high exotics'</p> <p>Temperate eucalypt woodlands with a heathy understorey: combination of 'secondary salinised' and 'rehabilitated salinised land'</p> <p>Temperate eucalypt woodlands with a heathy understorey: combination of 'reduced tree canopy' and 'unimproved pasture / modified woodlands, with a combination of 4 variants: 'high tree cover, moderate native plant diversity, moderate exotics', 'high tree cover, low native plant diversity, high exotics', 'thinned trees, moderate native plant diversity, moderate exotics', 'thinned trees, low native plant diversity, high exotics'</p> <p>Temperate eucalypt woodlands with a heathy understorey: unimproved pasture / modified woodlands, with a combination of 2 variants: 'sparse trees, moderate native plant diversity, moderate exotics' and 'sparse trees, low native plant diversity, high exotics'</p>	<p>ShrubGrassHighCover, ShrubGrassSparseCover, HeathySalinised, HeathyHighCover</p> <p>HeathySparseCover.</p>		
Acacia forests and woodlands	AcaciaForestsWoodlands	Acacia Forest and Woodland	Acacia
Casuarina forests and woodlands	CasuarinaForestsWoodlands	Casuarina Forest and Woodland	Casuarina
Melaleuca forests and woodlands	MelaleucaForestsWoodlands	Melaleuca Forest and Woodland	Melaleuca
Inland saline lake communities: reference	SalineLakeReference, SalineLakeSalinised, Wetlands, StreamMurray, StreamAvon, StreamCollie, StreamBlackwood, StreamMoore,	Not Modelled	-

ECOSYSTEM TYPE AND STATE	SHORT NAME (KHAN ET AL. 2023)	FULLCAM SPECIES GROWTH PARAMETER SET	FULLCAM PLOTFILE CODE
<p>Inland saline lake communities: combination of 'secondary salinised salt lakes' and 'rehabilitated salinised land'</p> <p>Wetlands</p> <p>Lowland streams: degraded lowland streams - Murray River</p> <p>Lowland streams: degraded lowland streams - Avon-Swan River</p> <p>Lowland streams: degraded lowland streams - Collie River</p> <p>Lowland streams: degraded lowland streams - Blackwood river</p> <p>Lowland streams: degraded lowland streams - Moore River</p> <p>Lowland streams: degraded lowland streams - Warren River</p> <p>Lowland streams: degraded lowland streams - Frankland River</p> <p>Lowland streams: degraded lowland streams - Pallinup River</p> <p>Lowland streams: degraded lowland streams - Bremer River</p> <p>Lowland streams: degraded lowland streams - Fitzgerald River</p>	StreamWarren, StreamFrankland, StreamPallinup, StreamBremer, StreamFitzgerald.		
Not applicable	NoData	No data	-

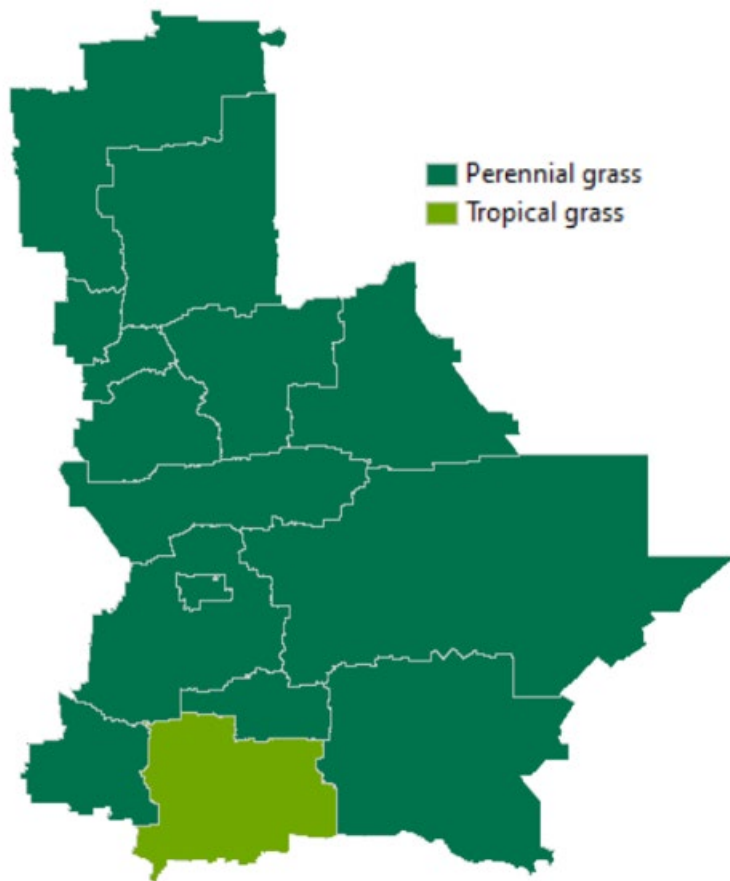


Figure 4 SA2-level FullCAM perennial grass species used in the simulations, as determined by spatial availability and state-level parameter sets within the FullCAM system

Step B. Generating unique sequences of fire events

Fire occurrence data were obtained from the Western Australia Department of Biodiversity, Conservation and Attractions DBCA-060 Fire History database (DBCA 2023). All fire extents were separated into either prescribed burns or wildfires for all events occurring from 1988 to 2021. The timing of each event was assigned to December of the corresponding fire season. This is consistent with the contemporary patterns of fire seasonality described by Russell-Smith et al. (2007), and constrained the number of fire events required to produce FullCAM plotfiles. Unique combinations of annual prescribed burns and wildfires were then summarised for each pixel between 1988 and 2020, yielding 2698 spatially unique fire histories. When implementing fire events in FullCAM, wildfires were simulated using the 'Wildfire-Moderate Severity' default event, and prescribed fires the 'Prescribed fire' default event. For agricultural vegetation, the 'Prescribed fire grass' default event was applied.

Step C. Generating unique sequences of land cover change

Across the entire spatial timeseries of changes in ecosystem state there were 20 unique state transitions detected (Table 2). All grid cells that were recorded as being '*Transformed*' at least once in the historical record were set to '*Transformed*' throughout (this simplification affected less than 0.03% of the total area). Across the whole WAW Domain, approximately 66% of the area showed a constancy in ecosystem type over the full period 1998-2020 (see Figure 6a).

The raw extent data defining the ecosystem types and changes in state, even after re-classifying to the 15 major FullCAM vegetation types (Table 1), still had in excess of 100,000 unique combinations of ecosystem state change across the spatial domain. However, many of those transitions are likely artefacts of the image processing as they indicate unrealistically rapid changes in pixel classification over time. For land cover transitions involving re-forestation there is a lag between the initiation of forest re-growth and the satellite detection of woody biomass cover. Here it was assumed that growth was initiated 10 years prior to its detection in the extent data (Paul and Roxburgh 2020).

To simplify the historical combinations of ecosystem state change and to facilitate analysis through reducing the required number of emulation models to a manageable number, a gap-filling filter was applied. This involved counting, for each pixel, the number of short-duration transitions (≤ 8 years) over the full period 1988-2020, and replacing these 'gaps' with the bounding land cover class. This procedure was implemented iteratively, starting with a 'gap' size of 1, then repeating the procedure with gap sizes from 2 to 8. In the case where the bounding cover classes differ, then the 'gap' was filled by selecting one of the bounding classes at random (Figure 5). Across the whole WAW region, this resulted in a simplification of the historical land cover classification to 1356 unique histories of ecosystem state change.

Table 2 Ecosystem state transitions detected across the WAW domain for the period 1988-2020, and the FullCAM approach to representing those transitions

Ecosystem codes are given in Table 1.

ECOSYSTEM STATE CHANGE	FULLCAM IMPLEMENTATION OF TRANSITION
Crop → Pasture	100% Crop harvest (clearing and stubble removal) followed by pasture establishment.
Crop → Reveg	100% Crop harvest (clearing and stubble removal) followed by establishment of Reveg.
Crop → MalleeMod	100% Crop harvest (clearing and stubble removal) followed by establishment of MalleeMod.
Crop → ShrublandMod	100% Crop harvest (clearing and stubble removal) followed by establishment of ShrublandMod.
Crop → WoodlandMod	100% Crop harvest (clearing and stubble removal) followed by establishment of WoodlandMod.
Pasture → Crop	100% pasture harvest event to facilitate Crop planting.
Pasture → Reveg	100% pasture harvest event to facilitate establishment of Reveg.
Pasture → EucForestLogged	100% pasture harvest event to facilitate establishment of EucForestLogged.
Pasture → MalleeMod	100% pasture harvest event to facilitate establishment of MalleeMod.
Pasture → ShrublandMod	100% pasture harvest event to facilitate establishment of ShrublandMod.
Pasture → WoodlandMod	100% pasture harvest event to facilitate establishment of WoodlandMod.
EucForestLogged → Pasture	100% forest harvest event followed by establishment of Pasture.
MalleeMod → Crop	100% forest harvest event followed by establishment of Crop.
MalleeMod → Pasture	100% forest harvest event followed by establishment of Pasture.
ShrublandMod → Crop	100% forest harvest event followed by establishment of Crop.
ShrublandMod → Pasture	100% forest harvest event followed by establishment of Pasture.
WoodlandMod → Crop	100% forest harvest event followed by establishment of Crop.
WoodlandMod → Pasture	100% forest harvest event followed by establishment of Pasture.
Reveg → Crop	100% forest harvest event followed by establishment of Crop.
Reveg → Pasture	100% forest harvest event followed by establishment of Pasture.

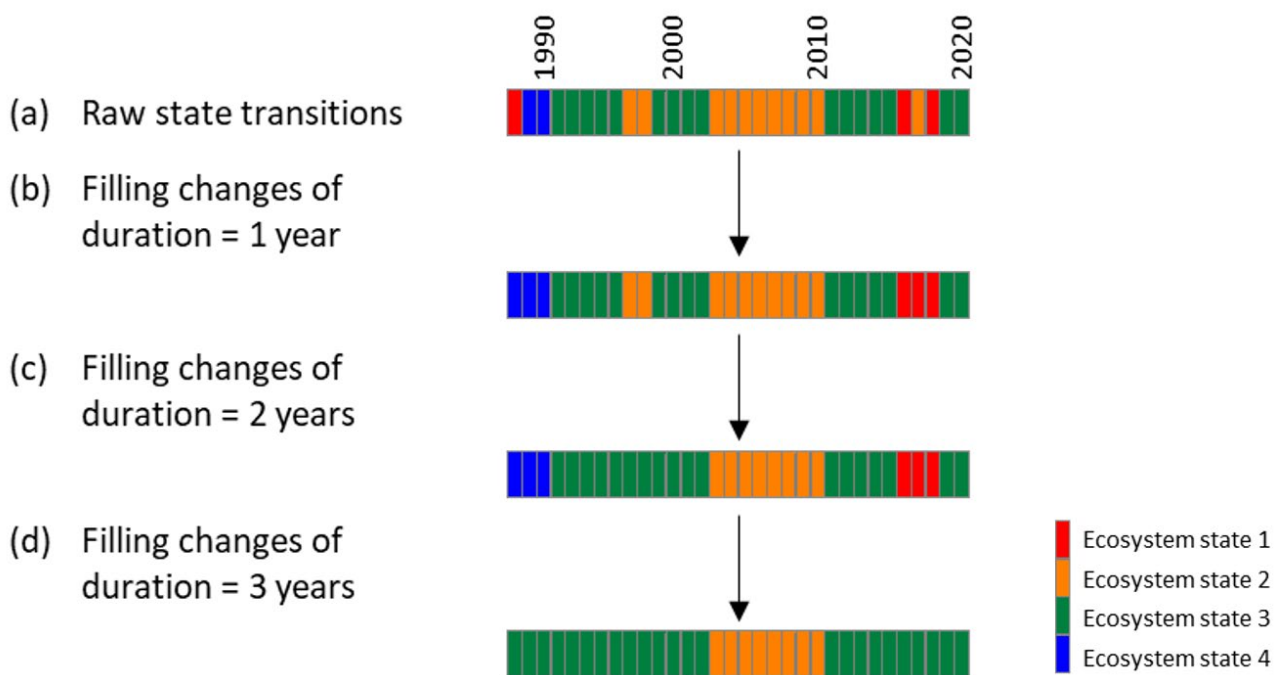


Figure 5 Flowchart for simplifying the unique ecosystem state changes: (a) original (unfiltered) history, with four states present, (b) – (d) The outcome of three successive filters to fill short-duration state persistence's of 1-3 years. The full application of the filter extended steps b-d to fill gaps of sizes up to 8 years

Step D. Generating FullCAM event queues and plotfiles

Intersecting the map of 1356 unique state transition histories (Figure 6a) with the map of 2698 unique fire histories yielded 10,896 unique combinations (Figure 6b). For FullCAM analysis, this therefore requires creating 10,896 separate FullCAM 'template' plotfiles, each populated with the appropriate species parameters, fire event timings (wildfire or prescribed fire, and associated grass fire) and ecosystem state change timings. The version of FullCAM used for the FNG simulations was v. 6.20.03.0827.

FullCAM simulations were initialised on June 30 1699 and were run at a monthly timestep until June 30 2021, with results saved at June 30 from 1987 to 2021. Although the reporting period is 1988-2020, the bounding years 1987 and 2021 were required in order to calculate the Net Ecosystem Carbon Balance. In the spin-up period between 1699 and 2002, the historical fire history (1988-2020) was repeated to ensure biomass, debris and soil carbon pools were appropriately equilibrated before the data recording period.

Ten FullCAM outputs were saved for further analysis (Table 3), from which seven additional variables were calculated (Table 4). From these, 11 variables were used for final reporting (Table 5).

Of the 10,896 unique state transition and fire history combinations, 9,472 were represented by less than 100 pixels across the whole spatial domain, corresponding to 0.8% the total area. Because the minimum sample size for emulation model fitting was 100 pixels, for these cases FullCAM was run directly, rather than via emulation. This reduced the total maximum number of emulation models that required fitting from 2,593,248 (10,896 unique combinations x 7 woody vegetation output variables x 34 years), to 338,912. A flow chart of the simulation is provided in

Figure 7. Example FullCAM outputs are shown in Figure 8, for three contrasting state change scenarios.

Table 3 List of FullCAM output variables saved

FULLCAM VARIABLE NAME	UNITS	DESCRIPTION
C mass of trees	tCO ₂ -e ha ⁻¹	Total living tree/shrub mass (above and below-ground)
C mass of crop	tCO ₂ -e ha ⁻¹	Total living crop/pasture mass (above and below-ground)
C mass of forest litter and deadwood	tCO ₂ -e ha ⁻¹	Total forest debris mass (above and below-ground)
C mass of forest standing dead	tCO ₂ -e ha ⁻¹	Total forest standing dead trees mass (above and below-ground)
C mass of agricultural debris	tCO ₂ -e ha ⁻¹	Total agricultural debris mass (above and below-ground)
C mass of soil	tCO ₂ -e ha ⁻¹	Total soil carbon mass
C mass sequestered due to production, to crop	tCO ₂ -e ha ⁻¹ yr ⁻¹	Total crop productivity integrated over one year
C mass sequestered due to production, to trees	tCO ₂ -e ha ⁻¹ yr ⁻¹	Total tree productivity integrated over one year
Emissions from fire_N2O and CH4	tCO ₂ -e ha ⁻¹ yr ⁻¹	Total non-CO ₂ emissions from fire
C mass emitted due to fire	tCO ₂ -e ha ⁻¹ yr ⁻¹	Total CO ₂ emissions from fire

Table 4 List of derived variables for reporting, and their calculation based on the quantities in Table 2

NECB = Net Ecosystem Carbon Balance; NPP = Net Primary Productivity

DERIVED VARIABLE	CALCULATION
Total fire emissions	‘Emissions from fire_N2O and CH4’ + ‘C mass emitted due to fire’
Total debris stock	‘C mass of forest litter and deadwood’ + ‘C mass of agricultural debris’ + ‘C mass of forest standing dead’
Total soil stock	‘C mass of forest soil’ + ‘C mass of agricultural soil’
Total ecosystem carbon stock	‘C mass of trees’ + ‘C mass of crop’ + ‘Total debris stock’ + ‘Total soil stock’
NPP	‘C mass sequestered due to production, to crop’ + ‘C mass sequestered due to production, to trees’
NECB	(‘Total ecosystem carbon stock’) _{Year t} - (‘Total ecosystem carbon stock’) _{Year t-1}
Heterotrophic respiration	‘NPP’ – ‘NECB’ – ‘C mass emitted due to fire’

Table 5 Final set of 11 variables used for reporting, and the file names for the associated mapped products

Derived variables from Table 3 are italicised, and FullCAM variables from Table 2 are shown in normal font.

VARIABLE	UNITS
C mass of trees	tCO ₂ -e ha ⁻¹
C mass of crop	tCO ₂ -e ha ⁻¹
<i>Total Debris stock</i>	tCO ₂ -e ha ⁻¹
<i>Total soil stock</i>	tCO ₂ -e ha ⁻¹
<i>Total ecosystem carbon stock</i>	tCO ₂ -e ha ⁻¹
Emissions from fire_N2O and CH4	tCO ₂ -e ha ⁻¹ yr ⁻¹
C mass emitted due to fire	tCO ₂ -e ha ⁻¹ yr ⁻¹
<i>Total fire emissions</i>	tCO ₂ -e ha ⁻¹ yr ⁻¹
<i>NPP</i>	tCO ₂ -e ha ⁻¹ yr ⁻¹
<i>NECB</i>	tCO ₂ -e ha ⁻¹ yr ⁻¹
<i>Heterotrophic respiration</i>	tCO ₂ -e ha ⁻¹ yr ⁻¹

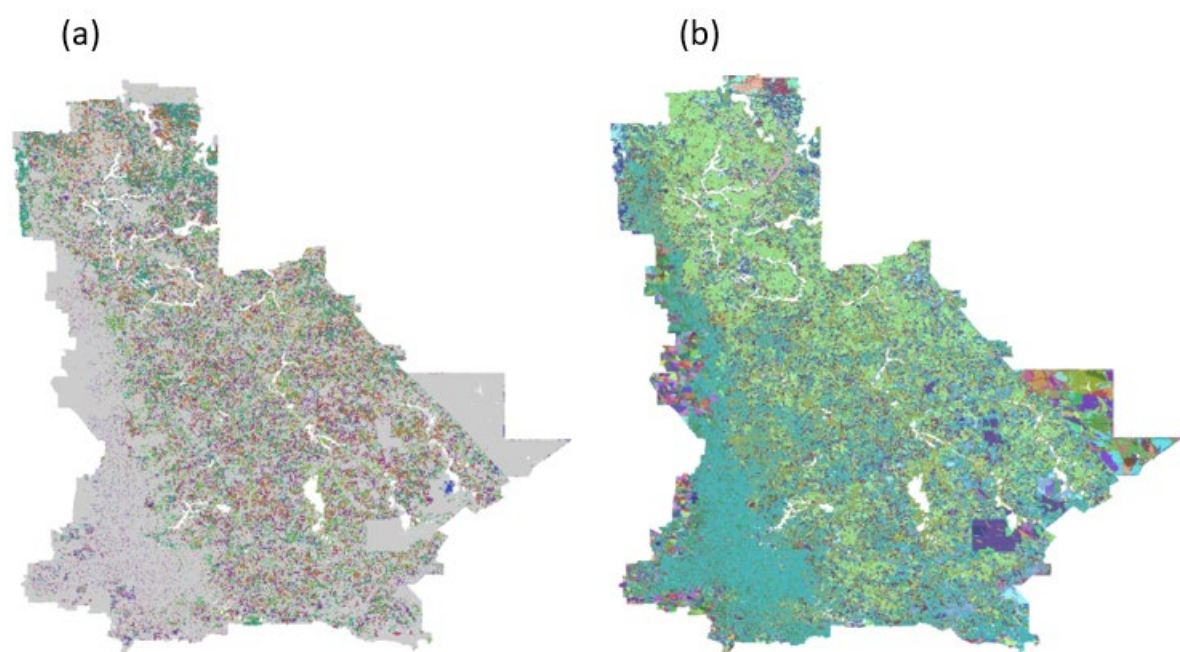


Figure 6 (a) Spatial distribution of the 1356 unique combinations of ecosystem state change history, with each colour representing a unique combination and grey represents grid cells with no state change over the period 1988-2020, comprising ~66% of the total area; (b) Spatial distribution of the 10,896 unique combinations of ecosystem state change history and fire history, with each colour representing a unique combination

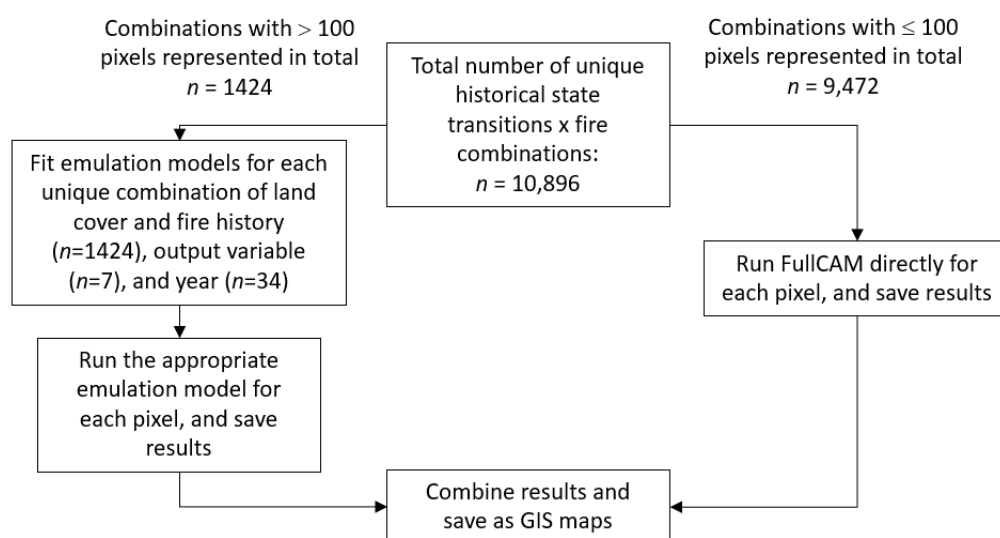


Figure 7 Summary flow chart of the overall analysis for the non-agricultural land cover classes, combining FullCAM model emulation (for cases where there are > 100 pixels represented across the MDB per unique combination of land cover and fire history) with direct runs of the FullCAM model, for those cases with insufficient data to support emulation model development and testing (≤ 100 pixels represented across the MDB per unique combination of land cover class and fire history)

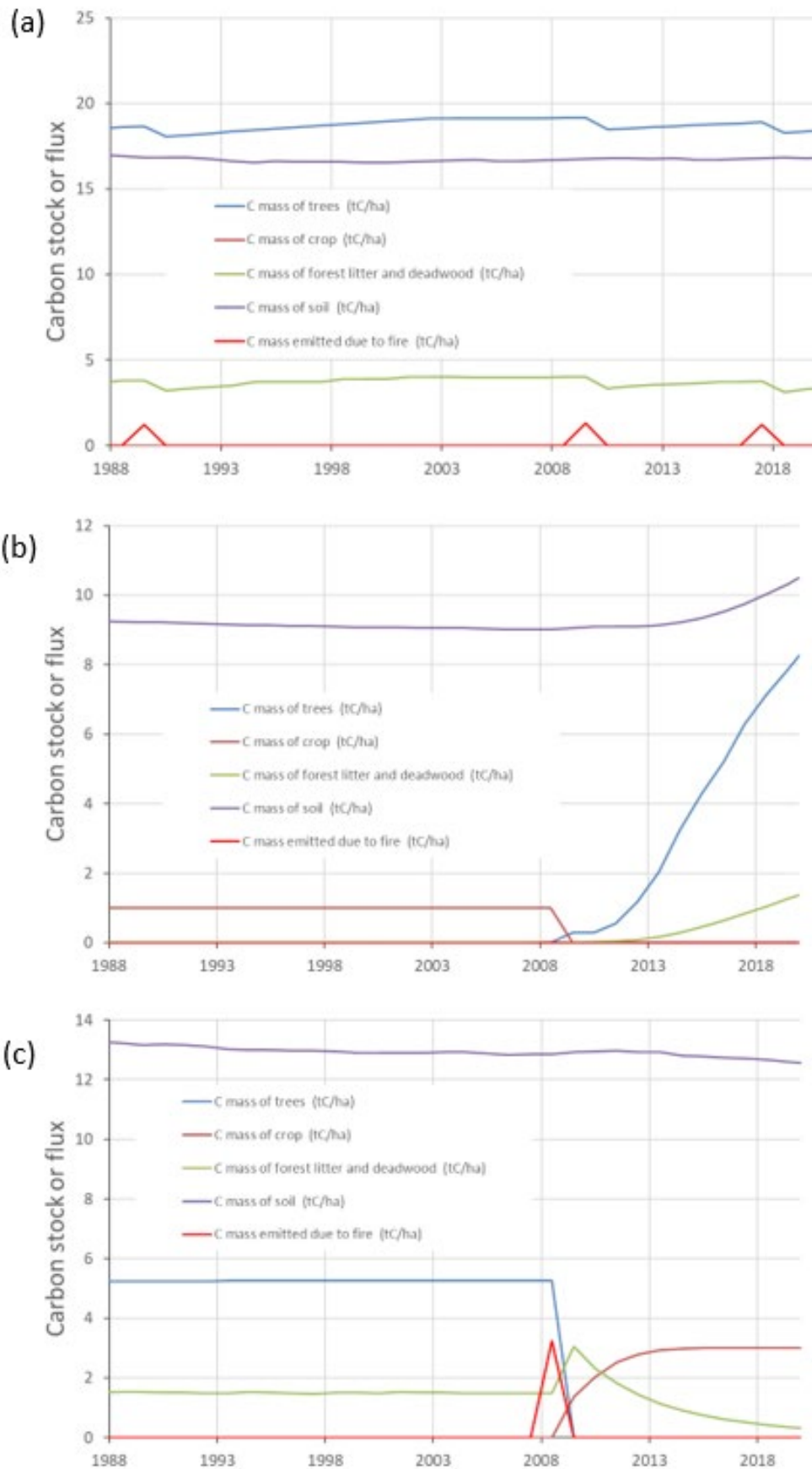


Figure 8 Example FullCAM output results for three of the 10,896 unique combinations of ecosystem state change and fire history depicting (a) Eucalyptus Open Forest in a reference state, (b) Crop with a transition in 2009 to a Mixed Species Environmental Planting, (c) Modified mallee with a transition to cropping in 2009

Note units are C, and not CO₂e

2.3 Data dictionary

The data products provided as part of this collection are described below. These were generated by applying the methods described in Section 2.2.

2.3.1 Raster data

Carbon mass of crops and pastures

Description: Carbon mass of crops and pastures (= perennial grass). This variable quantifies carbon stock at a specific date.

Variable type: Continuous

Units: tCO₂e ha⁻¹

Spatial reference: EPSG:9473, GDA2020 / Australian Albers

Spatial resolution: 100 m

Spatial extent: xmin: -1532000, xmax: -1060000, ymin: -3858000, ymax: -3319000

File format: GeoTIFF

File naming convention: WAW_ES_CropPastureC_tCO2e-ha_<YYYYMMDD>_v1.tif

Carbon mass of debris

Description: Carbon mass of debris. This variable quantifies carbon stock at a specific date.

Variable type: Continuous

Units: tCO₂e ha⁻¹

Spatial reference: EPSG:9473, GDA2020 / Australian Albers

Spatial resolution: 100 m

Spatial extent: xmin: -1532000, xmax: -1060000, ymin: -3858000, ymax: -3319000

File format: GeoTIFF

File naming convention: WAW_ES_DebrisC_tCO2e-ha_<YYYYMMDD>_v1.tif

Carbon mass of forests, woodlands and shrublands

Description: Carbon mass of forests, woodlands and shrublands. This variable quantifies carbon stock at a specific date.

Variable type: Continuous

Units: tCO₂e ha⁻¹

Spatial reference: EPSG:9473, GDA2020 / Australian Albers

Spatial resolution: 100 m

Spatial extent: xmin: -1532000, xmax: -1060000, ymin: -3858000, ymax: -3319000

File format: GeoTIFF

File naming convention: WAW_ES_ForestWoodlandShrublandC_tCO2e-ha_<YYYYMMDD>_v1.tif

Carbon mass of soil

Description: Carbon mass of soil. This variable quantifies carbon stock at a specific date.

Variable type: Continuous

Units: tCO₂e ha⁻¹

Spatial reference: EPSG:9473, GDA2020 / Australian Albers

Spatial resolution: 100 m

Spatial extent: xmin: -1532000, xmax: -1060000, ymin: -3858000, ymax: -3319000

File format: GeoTIFF

File naming convention: WAW_ES_SoilC_tCO2e-ha_<YYYYMMDD>_v1.tif

Total carbon mass

Description: Total carbon mass (crops, pastures, forests, woodlands, shrublands, debris and soil). This variable quantifies carbon stock at a specific date.

Variable type: Continuous

Units: tCO₂e ha⁻¹

Spatial reference: EPSG:9473, GDA2020 / Australian Albers

Spatial resolution: 100 m

Spatial extent: xmin: -1532000, xmax: -1060000, ymin: -3858000, ymax: -3319000

File format: GeoTIFF

File naming convention: WAW_ES_TotalC_tCO2e-ha_<YYYYMMDD>_v1.tif

Carbon dioxide emissions due to fire

Description: Total carbon dioxide (CO₂) emissions due to fire. This variable quantifies flux over a 1-year period.

Variable type: Continuous

Units: tCO₂e ha⁻¹ yr⁻¹

Spatial reference: EPSG:9473, GDA2020 / Australian Albers

Spatial resolution: 100 m

Spatial extent: xmin: -1532000, xmax: -1060000, ymin: -3858000, ymax: -3319000

File format: GeoTIFF

File naming convention: WAW_ES_FireEmissionsCO2_tCO2e-ha-yr_<YYYYMMDD>_<YYYYMMDD>_v1.tif

Nitrous oxide and methane emissions due to fire

Description: Total nitrous oxide (N₂O) and methane (CH₄) emissions due to fire. This variable quantifies flux over a 1-year period.

Variable type: Continuous

Units: tCO₂e ha⁻¹ yr⁻¹

Spatial reference: EPSG:9473, GDA2020 / Australian Albers

Spatial resolution: 100 m

Spatial extent: xmin: -1532000, xmax: -1060000, ymin: -3858000, ymax: -3319000

File format: GeoTIFF

File naming convention:

WAW_ES_FireEmissionsN2OCH4_tCO2e-ha-yr_<YYYYMMDD>_<YYYYMMDD>_v1.tif

Total emissions due to fire

Description: Total carbon dioxide (CO₂), nitrous oxide (N₂O) and methane (CH₄) emissions due to fire. This variable quantifies flux over a 1-year period.

Variable type: Continuous

Units: tCO₂e ha⁻¹ yr⁻¹

Spatial reference: EPSG:9473, GDA2020 / Australian Albers

Spatial resolution: 100 m

Spatial extent: xmin: -1532000, xmax: -1060000, ymin: -3858000, ymax: -3319000

File format: GeoTIFF

File naming convention:

WAW_ES_FireEmissionsTotal_tCO2e-ha-yr_<YYYYMMDD>_<YYYYMMDD>_v1.tif

Heterotrophic respiration

Description: Carbon losses due to decomposition of debris and soil by microorganisms. This variable quantifies flux over a 1-year period.

Variable type: Continuous

Units: tCO₂e ha⁻¹ yr⁻¹

Spatial reference: EPSG:9473, GDA2020 / Australian Albers

Spatial resolution: 100 m

Spatial extent: xmin: -1532000, xmax: -1060000, ymin: -3858000, ymax: -3319000

File format: GeoTIFF

File naming convention:

WAW_ES_HeterotrophicRespiration_tCO2e-ha-yr_<YYYYMMDD>_<YYYYMMDD>_v1.tif

Net Ecosystem Carbon Balance (NECB)

Description: The Net Ecosystem Carbon Balance is calculated as the difference in total carbon stocks between two periods of time. It embeds emissions from planned fires and wildfires, forest clearing and regrowth events and variability in vegetation growth and decay, in response to climatic variability. This variable quantifies flux over a 1-year period.

Variable type: Continuous

Units: tCO₂e ha⁻¹ yr⁻¹

Spatial reference: EPSG:9473, GDA2020 / Australian Albers

Spatial resolution: 100 m

Spatial extent: xmin: -1532000, xmax: -1060000, ymin: -3858000, ymax: -3319000

File format: GeoTIFF

File naming convention:

WAW_ES_NetEcosystemCBalance_tCO2e-ha-yr_<YYYYMMDD>_<YYYYMMDD>_v1.tif

Net Primary Productivity (NPP)

Description: Total mass of carbon sequestered due to primary production. This variable quantifies flux over a 1-year period.

Variable type: Continuous

Units: tCO₂e ha⁻¹ yr⁻¹

Spatial reference: EPSG:9473, GDA2020 / Australian Albers

Spatial resolution: 100 m

Spatial extent: xmin: -1532000, xmax: -1060000, ymin: -3858000, ymax: -3319000

File format: GeoTIFF

File naming convention:

WAW_ES_NetPrimaryProductivity_tCO2e-ha-yr_<YYYYMMDD>_<YYYYMMDD>_v1.tif

2.4 Accuracy, assumptions, and limitations

The FullCAM model and its associated data and parameters underpin Australia's National land sector Greenhouse Gas Accounting estimates that are reported annually to the United Nations under the requirements of the UNFCCC (DISER 2022). The model has therefore undergone extensive testing and validation during its development, as documented in a series of approximately 50 technical reports.⁴ The Australian Government is also committed to undertaking ongoing review and updates to FullCAM in response to new and developing science, and in response to regular external technical review from an independent international panel. Examples of recent improvements to the model include improved parameters for establishing overall site

⁴ <http://www.fullcam.com/FullCAMServer2020/Help/rep/s/>

productivity potential (Roxburgh et al. 2019), and improved growth calibrations for recovering and regenerating native vegetation (Paul and Roxburgh 2020), environmental and mallee plantings (Paul et al. 2015), and plantation forestry (Paul et al. 2022). In addition to scientific publications, documentation of the model improvements and their underlying assumptions are also summarised in the annual reports that are provided to the United Nations (DISER 2022; Appendices A-M).

Regarding accuracy, there are two components to consider. The first is bias, that measures whether predictions, on average, tend to underestimate or overestimate the true value. The second is precision, which is a measure of how much spread there is around the model predictions. As a national-scale accounting tool, model predictions have been shown to be unbiased at regional-to-continental scales (Paul et al. 2022; Roxburgh et al. 2019). However due to its relative simplicity and largely empirical nature, at any given location within the continent the model predictions are generally imprecise. For example, whilst the FullCAM-predicted maximum aboveground biomass is unbiased at both national and regional scales (Roxburgh et al. 2019), at any given location the mean absolute error, i.e. the expected average deviation from the actual value, is $\pm 73 \text{ tC ha}^{-1}$, or $\pm 43\%$ of the mean biomass.

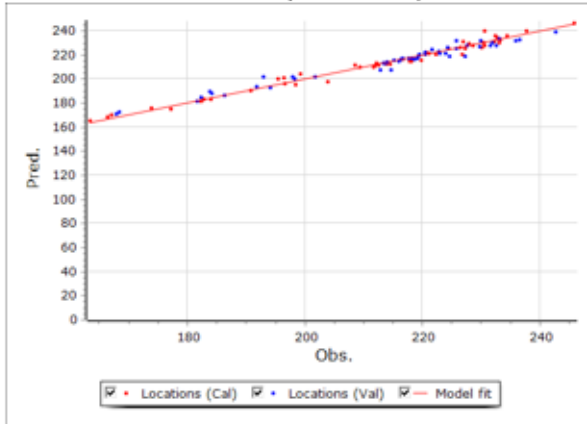
As described in Section 2.2, forest species and soil organic carbon in FullCAM were not able to be simulated directly due to a combination of the large study area, required map resolution, and computational limitations. Instead, for woody vegetation and soil carbon the model was emulated using simple linear regressions relating key input variables to FullCAM's output variables. The emulation model fit statistics (Table 6) and the example relationships between FullCAM and emulation model predictions (Figure 9) illustrate the high level of accuracy using the emulation approach, with Nash-Sutcliffe model efficiency and Lin's concordance values typically close to 1.0, indicating near-perfect predictions, and with Bias close to 0.0 for all output variables. Across all output variables soil carbon is the least well emulated, with RMSE of approximately $3\text{--}10 \text{ tCO}_2\text{-e ha}^{-1}$, or approximately 4% of the mean (compared to less than 1% for all other variables). It is possible the emulation performance for soil carbon may be improved by adding additional predictor variables into the emulation models, such as hydroclimatic variables.

Table 6 Validation statistics for spatial FullCAM emulation across the Western Australian Wheatbelt

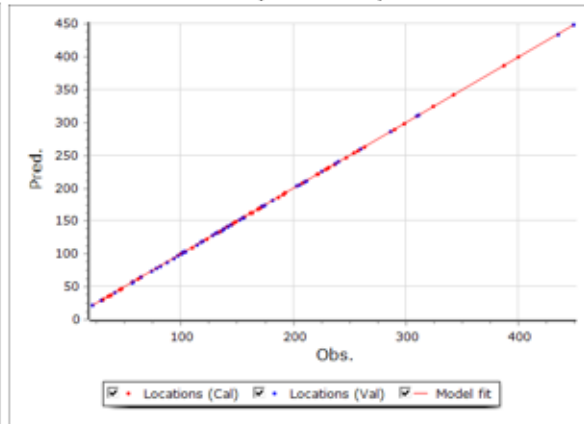
The statistics are the average of up to 50,505 fitted emulation models for each output variable, but excluding those emulation models fitted to constant data (e.g. tree mass is a constant 0.0 across space for a re-forestation simulation prior to the initiation of forest growth, as are fire emissions in years with no fire activity). Crop and pasture variables are not included in the table, as they are based in direct simulation of the FullCAM model

VARIABLE	NASH-SUTCLIFF EFFICIENCY	LIN'S CONCORDANCE COEFFICIENT	RMSE	RMSE (%)	BIAS	BIAS (%)	N EMULATION MODELS
C mass of trees (tCO ₂ -e ha ⁻¹)	0.998	0.999	0.247	0.320	-0.001	-0.001	35,587
C mass sequestered due to production, to trees (tCO ₂ -e ha ⁻¹ yr ⁻¹)	0.998	0.999	0.047	0.362	0.000	0.000	38,855
C mass of forest litter and deadwood (tCO ₂ -e ha ⁻¹)	0.998	0.999	0.226	0.624	0.000	0.000	38,742
C mass of forest standing dead (tCO ₂ -e ha ⁻¹)	1.000	1.000	0.001	0.054	0.000	0.000	18,650
C mass of soil (tCO ₂ -e ha ⁻¹)	0.882	0.838	6.921	4.102	-0.280	-0.172	50,505
C mass emitted due to fire (tCO ₂ -e ha ⁻¹ yr ⁻¹)	0.999	0.999	0.087	0.204	0.000	0.001	2,108
Emissions from fire (N ₂ O and CH ₄ ; tCO ₂ e ha ⁻¹ yr ⁻¹)	1.000	1.000	0.006	0.210	0.000	0.000	1,977

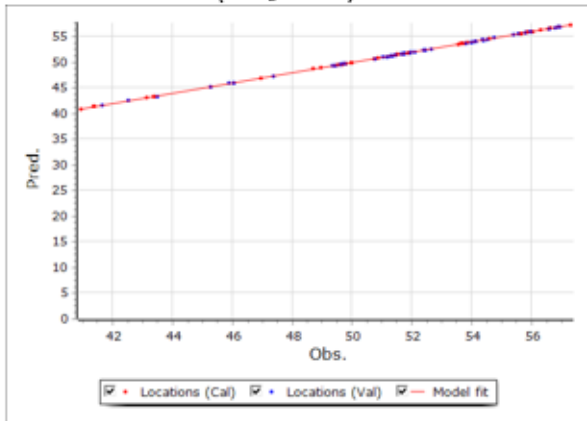
Forest soil carbon stock ($\text{tCO}_2\text{e ha}^{-1}$)



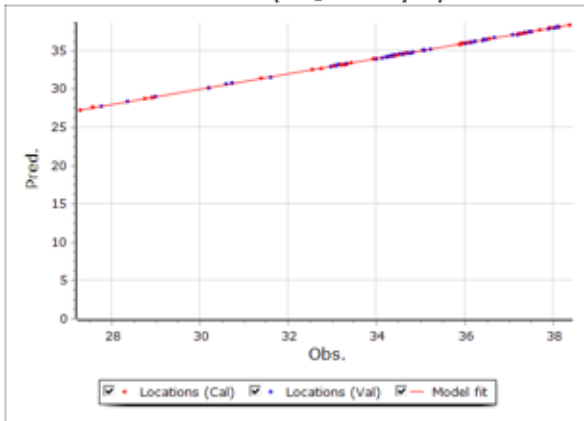
Total tree biomass ($\text{CO}_2\text{e ha}^{-1}$)



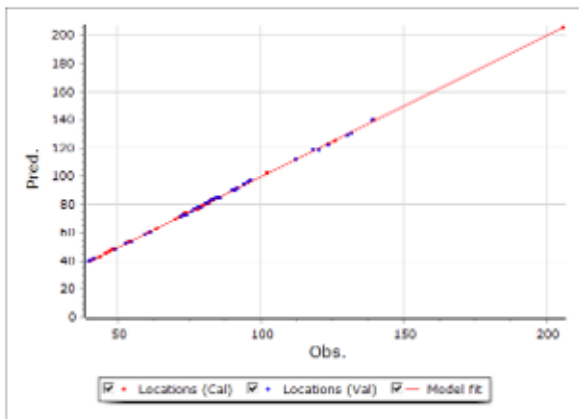
Total debris stock ($\text{tCO}_2\text{e ha}^{-1}$)



Production to trees ($\text{CO}_2\text{e ha}^{-1} \text{yr}^{-1}$)



Fire emissions (C) ($\text{tCO}_2\text{e ha}^{-1} \text{yr}^{-1}$)



Fire emissions (non- CO_2) ($\text{tCO}_2\text{e ha}^{-1}$)

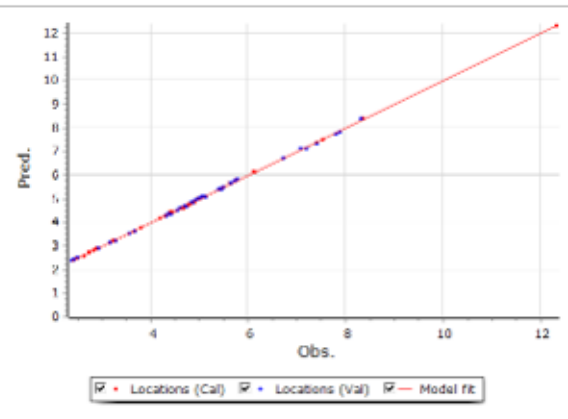


Figure 9 Example FullCAM predictions (x-axis, 'Obs') and emulation model predictions (y-axis, 'Pred') for a single unique land cover change x fire history combination

Red symbols are the 50 data points (locations) to which the emulation model was fitted, and blue data points are the 50 validation locations. The 1:1 line is shown, representing equivalence between FullCAM predictions and the corresponding emulation model predictions.

As with any modelling-based approach there are a number of assumptions, caveats, and opportunities for improvement. The most important of these are discussed below.

Net Ecosystem Carbon Balance (NECB)

NECB is a key variable, as it provides a summary of the total net ecosystem carbon balance (Chapin et al. 2006; Edens et al. 2019), with periods of positive NECB indicating net sequestration (and thus atmospheric draw-down of CO₂), and periods of negative NECB indicating net emissions to the atmosphere. In this analysis NECB included vegetation growth and turnover, debris accumulation and loss, and the dynamics of soil carbon. Regarding disturbances, NECB also includes carbon emissions from early- and late-dry-season fire. To simplify the analysis all early season fires were assumed to occur in May, and all late season fires in August. The accuracy of the prediction of these events could be improved through increasing the temporal resolution, noting the trade-off between increasing the temporal resolution of historical events and increased simulation complexity. Excluded from the NECB results were the impacts of other disturbances, such as flooding events, storm damage, or pests and diseases. Inclusion of these additional disturbances would lead to an increase in emissions to the atmosphere, and a decline in carbon stored in the landscape. The magnitude of these potential changes is difficult to assess, though sensitivity analyses of the FullCAM model suggests episodic events are minor components of total ecosystem emissions, relative to ongoing and continuous losses associated with the decomposition of dead organic matter, and soil respiration (Forrester et al. 2023).

Land cover and extent – data pre-processing assumptions

As described in Section 2.2 above, the land cover and ecosystem type data on which the FullCAM event queues were developed had to be simplified to reduce noise in the signal, and to reduce the number of unique land-cover histories to a level that could be realistically managed in the simulation environment. This involved reducing both the number of unique vegetation classes from 27 down to 15, and the number of unique land cover transitions at the pixel-level. For example, the filtering procedure in Figure 5 removed land cover transitions of short duration (≤ 8 years) on the basis such rapid transitions from forest cover to non-forest cover, and back again (and *vice versa*) are likely unrealistic. The validity of this assumption is difficult to test, with the most direct approach involving further validation of the extent data directly to remove unrealistic transitions, and to improve the confidence that the transitions that are detected are reflected in on-ground changes in ecosystem state, together with the associated implications for carbon storage and emissions. The implications of varying the assumptions embedded within the pre-processing steps are also difficult to assess, but could be addressed through numerical simulation via sequentially varying key parameters, such as the minimum time to define a transition, and then repeating the full analysis.

Land cover and extent– pre-simulation period

FullCAM simulations were initialised in the year 1800 to provide sufficient time for the carbon pools to stabilise prior to the reporting period (1988-2020), although stability was not formally tested. Additional analyses are required to explore the sensitivity of results to the initialisation assumptions, such as model spin-up period, and the inclusion of the disturbance events prior to the reporting period. Indeed, over the period 1800-1987 no land cover changes were applied, with the only modelled events being the repetition of the recently observed (2002-2020) fire scar

record. In reality, the carbon status of each location is not only a function of current conditions, but also prior history. In future applications, extension of land cover transitions and historic disturbance records to the pre-reporting model spin-up period, via the development of spatio-temporally defined management and disturbance histories, would allow historical events to be included in the simulations, and would improve the representation of past management and disturbance and its effects on current carbon dynamics. The implications on the terrestrial carbon balance of these additional analyses would be location-specific, depending upon e.g. the specific land use and land cover history at any given location, and could lead to either increases or decreases in carbon storage and emissions at the local scale, with the catchment-scale implications arising from the sum across all individual locations.

Spatial resolution

The emulation approach for running FullCAM can be applied at any spatial resolution. At the 100m resolution applied here certain landscape features, such as narrow (<30m wide) plantings of woody vegetation are only approximately represented. The development of new, high resolution spatial products, such as the TasCover tree mapping product (Stewart 2021) captures these finer scale features. Improving and applying these datasets will support and enhance running models like FullCAM at these finer spatial resolutions. Within the FullCAM system, the input data are provided at a range of resolutions, typically in the range 100m – 250m (DISER 2022). Undertaking analyses at finer spatial resolutions would not be expected to significantly change catchment-level indices such as total carbon storage and NECB, but would provide increased resolution at local scales that could provide additional information for identifying and attributing changes in ecosystem extent.

Simulation environment

One difficulty in applying the FullCAM model spatially, particularly across extensive areas and at fine spatial resolutions, is the need to develop additional, external code to interact with the model (as developed for this study). This is because the publicly available version of FullCAM is limited to analysing a single location at a time. Future public release versions of FullCAM may extend the current capabilities to allow full spatial analyses, but in the meantime, the requirement for additional software development to facilitate this capability limits widespread operationalisation of the model for spatial analysis.

Glossary

TERM	DEFINITION
Accounting component	A single part that helps the overall system of accounts gather relevant data, translate it into useful information, and communicate it. In ecosystem accounting, core accounting components include ecosystem extent, ecosystem condition, and ecosystem services.
Account-ready data	data that has been prepared such that it can be used nearly directly (with minimal additional processing) for compiling ecosystem accounts
Archetype models	Archetype models describe the endogenous disturbance dynamics and ecosystem expressions that characterise systems with ecosystem integrity. These models are not operational and cannot be directly or solely used for measurement or mapping but provide a conceptual guide for description of reference and modified states in state and transition models.
Basic spatial unit (BSU)	the smallest unit of aggregation that is used consistently across accounts and against which stocks and flows are recorded
Biodiversity	the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems (CBD 1992)
Biome	a biotic community finding its expression at large geographic scales, shaped by climatic factors and characterised by physiognomy and functional aspects, rather than by species or life-form composition (Mucina 2019; United Nations et al. 2021)
Community-level biodiversity	consideration of biodiversity for an assemblage of species within a taxonomic group at a location
Condition-hectares	derived as the sum of condition index values from the account-ready data within each Ecosystem Accounting Area (EAA) subdivision, reported in units of hectares. For ecologically meaningful interpretation, condition-hectares enables correct and consistent comparisons between years and EEAs
Ecological integrity	an ecosystem's capacity to maintain composition, structure, functioning and self-organisation over time using processes and elements characteristic for its ecoregion and within a natural range of variability (United Nations et al. 2021) (compare 'ecosystem integrity')
Economic unit	establishments (e.g. an individual business) that are aggregated by industry (e.g. agriculture, mining, manufacturing, health, education) and sector (e.g. corporations, households, and government). Referred to in the System of National Accounts (SNA) as 'institutional units'
Ecosystem	a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit (CBD 1992)
Ecosystem accounting area (EAA)	the geographical territory for which an ecosystem account is compiled (United Nations et al. 2021)
Ecosystem asset	a contiguous space of a specific ecosystem type characterized by a distinct set of biotic and abiotic components and their interactions (United Nations et al. 2021)
Ecosystem capacity	the ability of an ecosystem to generate an ecosystem service under current ecosystem condition, management and uses, at the highest yield or use level that does not negatively affect the future supply of the same or other ecosystem services from that ecosystem (United Nations et al. 2021)
Ecosystem condition	<p>the quality of an ecosystem measured in terms of its abiotic and biotic characteristics (United Nations et al. 2021)</p> <p>In the AusEcoModels Framework (Richards et al. 2020), ecosystem condition is a measure of ecosystem integrity including the capacity of ecosystem states to maintain biodiversity and ecosystem flows and connections. In the context of state and transition models it is defined as the departure of each ecosystem state from the reference state.</p> <p>The Habitat Condition Assessment System provides a condition score that represents the capacity of an area to provide the structures and functions necessary for the persistence</p>

TERM	DEFINITION
	of all species naturally expected to occur in that area if it were in an intact (or reference) state, and is calculated using departure from multiple locations in reference state (Williams et al. 2021).
Ecosystem condition index	composite indicators derived by aggregating from the combination of individual ecosystem condition indicators recorded in the ecosystem condition indicator account, using compatible reference levels from a common reference condition (United Nations et al. 2021, para. 5.81). Alternatively, this index may be derived using expert opinion.
Ecosystem condition indicator	rescaled version of ecosystem condition variables (United Nations et al. 2021)
Ecosystem condition characteristic	an ecosystem characteristic that is relevant for the assessment of ecosystem condition (United Nations et al. 2021)
Ecosystem condition typology	a hierarchical typology for organising data on ecosystem condition characteristics (United Nations et al. 2021)
Ecosystem condition variable	a quantitative metric describing individual characteristics of an ecosystem asset (United Nations et al. 2021)
Ecosystem conversion	situation in which, for a given location, there is a change in ecosystem type involving a distinct and persistent change in the ecological structure, composition and function which, in turn, is reflected in the supply of a different set of ecosystem services (United Nations et al. 2021)
Ecosystem expression	a distinct, recognisable, but transient phase within both the reference state and modified states of ecosystems. Each ecosystem state is dynamic and contains one to several ecosystem expressions, which have different ecosystem characteristics resulting from disturbance and biomass recovery processes.
Ecosystem extent	the area of an ecosystem asset in terms of spatial area (United Nations et al. 2021)
Ecosystem functional groups (EFG)	third level of the International Union for Conservation of Nature (IUCN) Global Ecosystem Typology (GET) classification. They are functionally distinctive groups of ecosystems within a biome and are defined in a manner consistent with the CBD definition of ecosystems (United Nations et al. 2021).
Ecosystem integrity	the level of intactness, completeness and integration in the structure, composition and function of an ecosystem with respect to the persistence of biodiversity. If a system is able to maintain its organisation (function and structure) over time in response to environmental disturbance cycles then it is said to have integrity (Kandziora et al. 2013; Kay 1991) (compare 'ecological integrity')
Ecosystem services	the contributions of ecosystems to the benefits that are used in economic and other human activity (United Nations et al. 2021)
Ecosystem site condition	The ecosystem site condition sub-index of ecosystem condition arises from an application of the Habitat Condition Assessment System (HCAS) which provides an estimate of habitat condition for an individual site, and further incorporates the negative landscape context effects of local pressures. Scores range from 0.0 (ecosystem integrity extinguished) to a maximum of 1.0 (ecosystem integrity in reference condition).
Ecosystem state	the observed ecosystem (including its structure, function and composition) at a particular point in space and time
Ecosystem state condition	The ecosystem state condition sub-index of ecosystem condition arises from an application of the Australian Ecosystem Models Framework that derives from eliciting expert knowledge of ecosystem reference and modified states for a specified set of ecosystem types, and their associated condition scores in the range from 0.0 (ecosystem integrity extinguished) to a maximum of 1.0 (ecosystem integrity in reference condition). Ecosystem state condition for each ecosystem type can be mapped using expert rules linking reference and modified ecosystem state characteristics to remotely-sensed variables.
Ecosystem type	In the SEEA EA standard: an ecosystem type reflects a distinct set of abiotic and biotic components and their interactions (United Nations et al. 2021). In AusEcoModels Framework: a unit of an ecosystem classification defined by the ecosystem characteristics (for example, facets of structure, function, composition) that

TERM	DEFINITION
	characterise the reference state for a given scale of organisation, for example defined by its discrete disturbance and recovery dynamic (Kay 1991; Richards et al. 2020). An ecosystem type, once defined, may be spatially identified and mapped.
Effective habitat area	The estimated total area of habitat within a region available for biodiversity, considering the ecosystem condition of each location (grid cell) within that region. Calculated as the area of the region multiplied by the average ecosystem condition of all grid cells within that region.
Gross Value Added (GVA)	a standard approach to measuring the value of production in national accounts. GVA is the value of the output at basic prices (the price received by the producer, adjusted for tax payable and subsidies receivable) less the value of intermediate consumption at purchasers' prices (the price paid by the producer for inputs, excluding any deductible tax) (ABS 2022).
Habitat condition	The habitat condition subindex of ecosystem site condition arises from an application of the Habitat Condition Assessment System (HCAS) which provides an estimate of habitat condition for an individual site. Scores range from 0.0 (ecosystem integrity extinguished) to a maximum of 1.0 (ecosystem integrity in reference condition). Habitat condition is the capacity of an area to provide the structures and functions necessary for the persistence of all species naturally expected to occur there, as if it were in a reference state (Williams et al. 2021).
Habitat Condition Assessment System	a method to remotely assess and map the generalised condition of natural habitat for terrestrial native biodiversity at a location against a reference condition derived from the dynamics of the most intact examples of native vegetation / ecosystems across contemporary Australia (Williams et al. 2021). Output is equivalent to an overall index of ecosystem condition in the SEEA EA framework
Inferred local pressures	The inferred local pressures sub-index of ecosystem site condition derives from an application of the Habitat Condition Assessment System (HCAS) as the distance-weighted average of the habitat condition sub-index, declining exponentially within a 2 km window to identify the negative landscape context effects of local pressures. Scores range from 0.0 (ecosystem integrity extinguished) to a maximum of 1.0 (ecosystem integrity in reference condition).
Integrity	see 'ecosystem integrity'
Managed additions or reductions	change in ecosystem assets predominantly attributable to actions by people in managing the land they occupy
Modified state	an ecosystem state that is not in reference condition, due to exogenous disturbances. Modified states are dynamic, and change between ecosystem expressions resulting from interactions between endogenous and exogenous disturbances (for example, natural flood events may shift expressions within a modified state in conjunction with managed environmental watering events).
Species persistence	the ongoing maintenance of a species as viable populations over the long term
Potential extent of occurrence	the area contained within the shortest continuous imaginary boundary that can be drawn to encompass all the current known localities, as well as inferred occurrence and projected original occurrence of a species (Brooks et al. 2019)
Reference condition	the condition against which past, present and future ecosystem condition is compared to in order to measure relative change over time (United Nations et al. 2021)
Reference level	the value of a variable at the reference condition, against which it is meaningful to compare past, present or future measured values of the variable (United Nations et al. 2021)
Reference site	a location in the landscape which is the least modified example of its ecosystem type and retains high ecosystem integrity
Reference state	the dynamic state of an ecosystem that has ecosystem integrity and is in reference condition. Archetype models are used as templates for the description of a reference state for a particular ecosystem type. Usually reference states refer to a local example of an ecosystem and contain more detailed quantitative information on ecosystem characteristics and endogenous disturbance regimes, compared to the archetype model.

TERM	DEFINITION
Reporting area	subdivision of the Ecosystem Accounting Area
Species-level biodiversity	consideration of biodiversity for each individual species separately
Species.hectares	unit for threatened species effective habitat and defined as the number of threatened species multiplied by the effective habitat area
Species richness	the number of species occurring in a location, typically considered within a specific taxonomic group
State and transition model	conceptual tool that describes the state of a particular ecosystem (which may vary, for example, from reference to degraded, in terms of ecosystem integrity), and the drivers or agents that cause transitions between states (Bestelmeyer et al. 2017; Stringham et al. 2003; Westoby et al. 1989). Transitions between states occur as a result of the introduction of new exogenous disturbance regimes, the transformation of transient disturbances into persistent disturbances, and/or changes to reference disturbance regimes (resulting in a shift to an exogenous disturbance), altering environmental conditions and resources available to constituent species. These changes may be directly caused by recent anthropogenic modification of local habitats (e.g. vegetation thinning or clearing, stock grazing, introduction of native or alien invasive species), or may result from recent and rapid climate change (i.e. an indirect anthropogenic driver). Transitions in state and transition models are difficult to reverse without application of intensive management, an extreme event or long timeframe (Bestelmeyer et al. 2017, 2009), and are distinguished from pathways between different ecosystem expressions within a state, which often result from slow-acting but incremental successional processes (Rumpff et al. 2011).
Stock account	a way of recording information about the quality or quantity and changes (additions and reductions) of ecosystem assets between temporal units (e.g. years)
Supply and use table (SUT)	the ecosystem services reported in supply and use tables will be equal to the actual flow between the ecosystem assets and economic units. The flow of ecosystem services can be measured in either biophysical terms (in biophysical supply and use tables) or in monetary terms (in monetary supply and use tables)
System of National Accounts (SNA)	an internationally agreed standard method of collecting, organising, and reporting information on national economic activity
SNA benefits and Non-SNA benefits	Some ecosystem services contribute to benefits that are delivered as goods and services within the economy (e.g. food, timber, water). These benefits are already included within the System of National Accounts (SNA) and are termed 'SNA benefits' and already form part of measures such as gross domestic product (GDP). Other ecosystem services contribute to benefits that are not within the production boundary of the SNA (e.g. clean air, flood protection or water filtration provided by ecosystems). These benefits are termed 'non-SNA benefits' (United Nations et al. 2021 section 6.2.2, p.123).
Thematic account	Standalone accounts, or sets of accounts, that organise data around specific policy-relevant themes, such as accounting for biodiversity, carbon and oceans, or protected areas, wetlands, forests and urban areas.
Transition	change between ecosystem states
Trend	qualitative or quantitative assessment of the general direction of change (e.g. increasing, decreasing, steady) that is developing based on a time-series of measurements
Unmanaged additions or reductions	change in ecosystem assets predominantly attributable to natural system processes and dynamics such as climatic variability, fire regimes and biotic interactions
Umbrella class	group of archetype models in the AusEcoModels Framework (Richards et al. 2020) that is compatible with Major Vegetation Groups in the National Vegetation Information System (NVIS) (NVIS Technical Working Group 2017)
Variant	Different form of a state, similar to an expression within a state except that variants are alternatives rather than part of a dynamic. Variants share the same drivers and general characteristics of the state but vary in their exact structural form or species composition. For example, they may reflect categories along a gradient (e.g. degree of tree cover or understorey degradation, driven by degree of tree clearing or livestock grazing). Variants

TERM	DEFINITION
	are used to acknowledge variation within states whilst avoiding the significant complexity that would be introduced by treating them as separate states.

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Suite of technical outputs for *Ecosystem Accounting Pilots for Agricultural and Mixed-Use Landscapes* project: Western Australian Wheatbelt project

Engagement and communication outputs

First Nations engagement and recommendations

Woodward E, Jarvis D, Grainger D, Ewamian Ltd, Ewamian People Aboriginal Corporation RNTBC, Tagalaka Aboriginal Corporation RNTBC, Kooyar Wongi Pty Ltd, Schmidt RK and Tetreault-Campbell S (2023) Regional Ecosystem Accounting Pilot projects: First Nations engagement on ecosystem models and recommendations. A report from the Regional Ecosystem Accounting Pilot projects. CSIRO.
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Synthesis and summary reports

Richards AE*, Brandon C*, Liu N, Mokany K, Schmidt RK, Smith GS, Williams KJ, Evans D, Ferrier S, Geffersa A, Giljohann KM, Harwood TD, Hayward J, Johnson S, Jordan R, Khan S, Lehmann EA, Liedloff AC, Luxton S, Macfadyen S, Murphy HT, Newnham G, Pascoe S, Prober S, Roxburgh SH, Scheufele G, Stewart SB, Szetey K, Tetreault-Campbell S, Ware C and Woodward E (2023) Experimental ecosystem accounts for the Western Australian Wheatbelt. A synthesis report from the Regional Ecosystem Accounting Pilot projects. CSIRO.
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*co-lead authors, followed by sub-project leads alphabetically, then all other co-authors alphabetically

Brandon C*, Richards AE*, Liu N, Mokany K, Schmidt RK, Smith GS, Williams KJ, Evans D, Ferrier S, Geffersa A, Giljohann KM, Harwood TD, Hayward J, Johnson S, Jordan R, Khan S, Lehmann EA, Liedloff A, Luxton S, Macfadyen S, Murphy HT, Newnham G, Pascoe S, Prober S, Roxburgh SH, Scheufele G, Stewart SB, Szetey K, Tetreault-Campbell S, Ware C and Woodward E (2023) Experimental ecosystem accounts for the Western Australian Wheatbelt. A summary report from the Regional Ecosystem Accounting Pilot projects. CSIRO. <https://publications.csiro.au/publications/publication/Plcsiro:EP2023-3510>

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Summary of input data

Richards AE, Brandon C, Liu N, Mokany K, Schmidt RK, Smith GS, Williams KJ, Evans D, Ferrier S, Geffersa A, Giljohann KM, Harwood TD, Hayward J, Johnson S, Jordan R, Khan S, Lehmann EA, Liedloff AC, Luxton S, Macfadyen S, Murphy HT, Newnham G, Pascoe S, Prober S, Roxburgh SH, Scheufele G, Stewart SB, Szetey K, Tetreault-Campbell S, Ware C and Woodward E (2023) Input data for experimental ecosystem accounts for the Western

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Overarching data collection for the Western Australian Wheatbelt

Richards AE, Schmidt RK, Liu N, Mokany K, Smith GS, Williams KJ, Evans D, Ferrier S, Giljohann KM, Harwood TD, Hayward J, Johnson S, Jordan R, Khan S, Lehmann EA, Liedloff AC, Luxton S, Macfadyen S, Murphy HT, Newnham G, Ogden G, Prober SM, Roxburgh SH, Stewart SB, Szetey K, Tetreault-Campbell S, Ware C, Wiehl G and Woodward E (2023) Experimental ecosystem accounts and supplementary data for the Western Australian Wheatbelt. A data collection from the Regional Ecosystem Accounting Pilot projects. CSIRO. Data Collection. <https://data.csiro.au/collection/csiro:57811>

Data quality statement

Stewart SB, Schmidt RK, Liu N, Richards AE, Mokany K, Smith GS, Williams KJ, Evans D, Ferrier S, Giljohann KM, Harwood TD, Hayward J, Johnson S, Jordan R, Khan S, Lehmann EA, Liedloff AC, Luxton S, Macfadyen S, Murphy HT, Newnham G, Ogden G, Prober SM, Roxburgh SH, Szetey K, Tetreault-Campbell S, Ware C, Wiehl G and Woodward E (2023) Data quality statement: experimental ecosystem accounts for the Western Australian Wheatbelt. In: Experimental ecosystem accounts and supplementary data for the Western Australian Wheatbelt. A data collection from the Regional Ecosystem Accounting Pilot projects. CSIRO. Data Collection. <https://data.csiro.au/collection/csiro:57811>

Methods for developing Basic Spatial Units, Ecosystem Accounting Area and reporting areas

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Conceptual models

Overarching data collection

Prober SM, Jordan R, Richards AE, Tetreault-Campbell S, Hayward J, Liedloff AC, Luxton S, Macfadyen S, Szetey K, Woodward E and Schmidt RK (2023) Ecosystem classification and conceptual models for the Western Australian Wheatbelt. A data collection from the Regional Ecosystem Accounting Pilot projects. CSIRO. Data Collection. <https://data.csiro.au/collection/csiro:57829>

Methods for developing conceptual models

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Ecosystem states and expressions

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Expert-elicited condition scores

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Description of transitions

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Conceptual models: diagrams and images

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Ecosystem extent

Methods for developing account-ready data

Khan S, Newnham G, Richards AE, Johnson S, Murphy HT, Prober SM, Jordan R, Ogden G, Wiehl G, Liu N, Tetreault-Campbell S and Schmidt RK (2023) Methods for developing account-ready data: ecosystem extent in the Western Australian Wheatbelt. In: Account-ready data: ecosystem extent in the Western Australian Wheatbelt. A data collection from the Regional Ecosystem Accounting Pilot projects. CSIRO. Data Collection. <https://data.csiro.au/collection/csiro:59265>

Account-ready data

Khan S, Newnham G, Richards AE, Johnson S, Murphy HT, Prober SM, Jordan R, Ogden G, Wiehl G, Liu N, Tetreault-Campbell S and Schmidt RK (2023) Account-ready data: ecosystem extent in the Western Australian Wheatbelt. A data collection from the Regional Ecosystem Accounting Pilot projects. CSIRO. Data Collection. <https://data.csiro.au/collection/csiro:59265>

Methods for compiling accounts

Richards AE, Khan S, Newnham G, Liu N, Johnson S, Prober SM, Jordan R, Stewart SB, Tetreault-Campbell S and Schmidt RK (2023) Methods for compiling accounts: ecosystem extent in the Western Australian Wheatbelt. In: Experimental ecosystem accounts and supplementary data for the Western Australian Wheatbelt. A data collection from the Regional Ecosystem Accounting Pilot projects. CSIRO. Data Collection.
<https://data.csiro.au/collection/csiro:57811>

Experimental ecosystem accounts and supplementary data

Richards AE, Khan S, Newnham G, Liu N, Johnson S, Prober SM, Jordan R, Tetreault-Campbell S and Schmidt RK (2023) Experimental ecosystem accounts and supplementary data by ecosystem functional groups: ecosystem extent in the Western Australian Wheatbelt. A data collection from the Regional Ecosystem Accounting Pilot projects. CSIRO. Data Collection.
<https://data.csiro.au/collection/csiro:57811>

Richards AE, Khan S, Newnham G, Liu N, Johnson S, Prober SM, Jordan R, Tetreault-Campbell S and Schmidt RK (2023) Experimental ecosystem accounts and supplementary data by ecosystem functional groups (time series): ecosystem extent in the Western Australian Wheatbelt. A data collection from the Regional Ecosystem Accounting Pilot projects. CSIRO. Data Collection. <https://data.csiro.au/collection/csiro:57811>

Richards AE, Khan S, Newnham G, Liu N, Johnson S, Prober SM, Jordan R, Tetreault-Campbell S and Schmidt RK (2023) Experimental ecosystem accounts and supplementary data by ecosystem types and states: ecosystem extent in the Western Australian Wheatbelt. A data collection from the Regional Ecosystem Accounting Pilot projects. CSIRO. Data Collection.
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Richards AE, Khan S, Newnham G, Liu N, Johnson S, Prober SM, Jordan R, Tetreault-Campbell S and Schmidt RK (2023) Experimental ecosystem accounts and supplementary data by ecosystem types and states (time series): ecosystem extent in the Western Australian Wheatbelt. A data collection from the Regional Ecosystem Accounting Pilot projects. CSIRO. Data Collection. <https://data.csiro.au/collection/csiro:57811>

Richards AE, Khan S, Newnham G, Liu N, Johnson S, Prober SM, Jordan R, Tetreault-Campbell S and Schmidt RK (2023) Experimental ecosystem accounts and supplementary data by Statistical Areas Level 2: ecosystem extent in the Western Australian Wheatbelt. A data collection from the Regional Ecosystem Accounting Pilot projects. CSIRO. Data Collection.
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Areas Level 2 (change matrix): ecosystem extent in the Western Australian Wheatbelt. A data collection from the Regional Ecosystem Accounting Pilot projects. CSIRO. Data Collection. <https://data.csiro.au/collection/csiro:57811>

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Ecosystem condition

Methods for developing account-ready data

Williams KJ, Giljohann KM, Liu N, Harwood TD, Lehmann EA, Ferrier S, Richards AE, Prober SM, Hayward J, Jordan R, Khan S, Ware C, Stewart SB, Tetreault-Campbell S and Schmidt RK (2023) Methods for developing account-ready data: ecosystem condition in the Western Australian Wheatbelt. In: Account-ready data: ecosystem condition in the Western Australian Wheatbelt. A data collection from the Regional Ecosystem Accounting Pilot projects. CSIRO. Data Collection. <https://data.csiro.au/collection/csiro:59266>

Account-ready data

Giljohann KM, Harwood TD, Lehmann EA, Liu N, Williams KJ, Ferrier S, Richards AE, Prober SM, Hayward J, Jordan R, Khan S, Ware C, Donohue R, Stewart SB, Tetreault-Campbell S and Schmidt RK (2023) Account-ready data: ecosystem condition in the Western Australian Wheatbelt. A data collection from the Regional Ecosystem Accounting Pilot projects. CSIRO. Data Collection. <https://data.csiro.au/collection/csiro:59266>

Methods for compiling accounts

Williams KJ, Liu N, Giljohann KM, Ferrier S, Harwood TD, Lehmann EA, Richards AE, Stewart SB, Tetreault-Campbell S and Schmidt RK (2023) Methods for compiling accounts: ecosystem condition in the Western Australian Wheatbelt. In: Experimental ecosystem accounts and supplementary data for the Western Australian Wheatbelt. A data collection from the Regional Ecosystem Accounting Pilot projects. CSIRO. Data Collection. <https://data.csiro.au/collection/csiro:57811>

Experimental ecosystem accounts and supplementary data

Liu N, Giljohann KM, Williams KJ, Ferrier S, Harwood TD, Lehmann EA, Richards AE, Stewart SB, Tetreault-Campbell S and Schmidt RK (2023) Experimental ecosystem accounts and supplementary data by ecosystem types: ecosystem condition in the Western Australian Wheatbelt. In: Experimental ecosystem accounts and supplementary data for the Western Australian Wheatbelt. A data collection from the Regional Ecosystem Accounting Pilot projects. CSIRO. Data Collection. <https://data.csiro.au/collection/csiro:57811>

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Biodiversity

Methods for developing account-ready data

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Account-ready data

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