Experimental ecosystem accounts for the Gunbower-Koondrook-Perricoota Forest Icon Site

A report from the Land and Ecosystem Accounts Project

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Source: John Baker, DAWE. Gunbower Creek flowing through Gunbower Forest near Cohuna.

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Acronyms

Acronym	Definition
AusEcoModels Framework	Australian Ecosystem Models Framework
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAWE	Department of Agriculture, Water and the Environment
GKP	Gunbower-Koondrook-Perricoota Forest Icon Site
IDEEA	Institute for Development of Environmental-Economic Accounting
IUCN	International Union for Conservation of Nature
LEAP	Land and Ecosystem Accounts Project
MDBA	Murray–Darling Basin Authority
MJA	Marsden Jacob Associates
Project	Valuing Parks Case Study Project
SEEA EA	System of Environmental-Economic Accounting – Ecosystem Accounting
SNA	System of National Accounts
TLM	The Living Murray
UNCEEA	United Nations Committee of Experts on Environmental-Economic Accounting

Contributors

The Valuing Parks Case Study Project (the Project) is part of the Land and Ecosystem Accounts Project (LEAP), progressing under the national strategy for a common national approach to environmental-economic accounting (IJSC 2018), governed by the Environmental-Economic Accounts Board. Leaders of each sub-project are underlined.

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- ecosystem extent (Richards et al. 2021b): Michael Vardon and Juan Guerschman
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- biodiversity (Mokany et al. 2021a): Hedley Grantham and Kristen Williams.

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Summary

Environmental-economic accounting involves recording, organising and communicating the linkages between environmental, cultural, social and economic information.

The information in this report forms part of an ecosystem accounting case study aiming to progress the national strategy for a common national approach to environmental-economic accounting (IJSC 2018). The case study site is the Gunbower-Koondrook-Perricoota Forest Icon Site (GKP). Gunbower Forest is located on the Victorian side of the icon site and includes national parks managed by Parks Victoria and state forest managed by the Victorian Department of Environment, Land, Water and Planning. Koondrook-Perricoota Forest is located in NSW and is made up of several state forests managed by Forestry Corporation NSW (FCNSW). Through Ramsar listing of the Gunbower site in 1982, and Koondrook-Perricoota (under the NSW Central Murray Forests Ramsar site) in 2003, and the *Water Act 2007*, the Australian Government also has a role in management, which can be exercised through the Murray-Darling Basin Authority (MDBA).

GKP is also one of 6 icon sites that are regularly monitored under The Living Murray (TLM) program, established in 2002 to maintain their ecological health. Icon sites in the TLM program are identified as priority environmental assets in the long-term watering plans developed by Murray-Darling Basin state governments as part of the Basin Plan (MDBA 2018). Under the TLM program, the North Central Catchment Management Authority is responsible for coordinating the delivery of environmental water in the Gunbower Forest. FCNSW coordinates the delivery of environmental water to Koondrook-Perricoota Forest.

This summary provides an overview of the ecosystem accounting results. Information on data used and methods applied can be found in the body of this report and in accompanying technical reports. It is important to understand the limitations of the approaches taken to producing the accounting outputs before the results are used.

Ecosystem extent

Ecosystem extent is a measure of the total area of different ecosystems in GKP. Key findings include:

- GKP covers an area of 56,020 ha, comprising the Victorian Gunbower Forest (21,066 ha) and NSW Koondrook-Perricoota Forest (34,954 ha).
- 'Inland floodplain eucalypt forests and woodlands' was the dominant ecosystem type in 2010 and 2015, making up approximately 85% of the total area of GKP in both years.
- Wetlands were the second most dominant with a share of approximately 10% in both years.
- Between 2010 and 2015, the largest changes in extent were in:
    - inland floodplain eucalypt forests and woodlands (net decrease of 675 ha relative to 2010, about 1.5% of the 2015 extent)
    - wetlands (net increase of 808 ha relative to 2010, about 14% of the 2015 extent).

Ecosystem condition

Ecosystem condition accounting focusses on the measurement of the quality (ecological integrity) of ecosystems within the accounting area. Key findings include:

- The ecosystem condition index shows GKP, in general, to be in moderate condition, with aggregated mean scores of 0.498 and 0.481 for 2010 and 2015, respectively, on a scale from 0.0 (ecosystem completely removed) to 1.0 (ecosystem in reference condition).
- The largest changes in condition were observed in the 'inland eucalypt floodplain forests and woodlands' ecosystem type and 'cultivated areas'. The former was a negative change and the latter was a positive change.
- Two ecosystem types, 'wetlands' and 'fire-intolerant *Callitris* woodlands', show no apparent change in ecosystem condition over the period.
- These small changes in ecosystem condition are unsurprising given ecological timeframes are long, and major changes in condition are not expected to manifest over a 5-year time frame.

Ecosystem services

Ecosystem services are transactions between ecosystems and economic units such as households, government and industry. A subset of the ecosystem services that GKP provides were measured quantitatively and qualitatively during the project, including:

- provisioning services – biomass for timber and firewood (quantitatively), floral resources for honey production (quantitatively) and floral resources for hive building (qualitatively)
- regulating services – global carbon sequestration and stock (quantitatively), water flow regulation (qualitatively)
- cultural services – ecosystem services and First Nations Australians (qualitatively) and recreation-related services (quantitatively).

Ecosystem and species appreciation flows (quantitatively) were also measured despite not meeting the criteria for an ecosystem service under the United Nations System of Environmental-Economic Accounting.

The key findings include:

- 47,988 total tonnes of biomass for timber were harvested across the GKP in 2010, dropping to 9,027 tonnes of total yield in 2015. Biomass for timber was harvested from only the 'inland floodplain eucalypt forests and woodlands' ecosystem type.
- Timber harvested in 2010 had a total monetary value of around $868,000. Of this total, $66,000 was supplied by the Gunbower Forest and $802,000 by the Koondrook-Perricoota Forest.
- In 2010 and 2015, the total firewood yield across GKP was 74,131 tonnes and 57,937 tonnes, respectively. All firewood was harvested from the 'inland floodplain eucalypt forests and woodlands' ecosystem type and is allocated to the local firewood industry.
- Total biomass for firewood harvested in 2010 has a residual rent of around $1,482,000. The total residual rent of harvest from GKP in 2015 is around $1,159,000.

- The total supply of carbon sequestration services was 1,022,807 tonnes/ha in 2010 and 1,030,771 tonnes/ha in 2015.
- The 2010 total monetary supply and use of carbon sequestration relying on exchange values from the World Bank Carbon Pricing Dashboard was around $71 million. Inland floodplain eucalypt forests and woodlands supplied around $25.1 million and $42.2 million of monetary supply and use across Gunbower Forest and Koondrook-Perricoota Forest respectively.
- The 2015 total monetary supply and use of carbon sequestration relying on ACCU exchange values from the World Bank Carbon Pricing Dashboard was around $94 million. Inland floodplain eucalypt forests and woodlands supplied around $35.6 million and $53.6 million of monetary supply and use across Gunbower Forest and Koondrook-Perricoota Forest respectively.
- There was a total of 44,812 and 28,597 ha of habitat suitable for 8 focal species in 2010 and 2015 respectively.
- Between 2010 and 2015 there was a reduction in area of habitat for the8 focal species across the whole GKP site. The greatest reduction in habitat for these focal species was 11,909 ha from 'inland floodplain eucalypt forests and woodlands' ecosystem type in Koondrook-Perricoota. The largest decrease in habitat for the 8 focal species in Gunbower was 2,929 ha from 'inland floodplain eucalypt forests and woodlands' ecosystem type.
- Ecosystem and species appreciation in 2010 had a total exchange value of around $150 million. The 'inland floodplain eucalypt forests and woodland' ecosystem type provides the largest proportion of value in both 2010 and 2015. In 2010, this ecosystem type provided around $46.5 million of exchange value from Gunbower and around $71.2 million from Koondrook-Perricoota.
- In 2015, the total ecosystem and species appreciation exchange value fell to around $113 million. In 2015, the 'inland floodplain eucalypt forests and woodlands' ecosystem type provided around $30.4 million of exchange value from the Gunbower and around $45.2 million from Koondrook-Perricoota.
- In 2010, total visit days to Gunbower and Koondrook-Perricoota are estimated at 211,000. In 2015, total visit days to Gunbower and Koondrook-Perricoota are estimated at 340,000. Around three-quarters of total visit days are in Gunbower National Park.
- In 2010, consumption expenditure attributable to Gunbower and Koondrook-Perricoota is estimated at $14.3 million. In 2015, consumption expenditure attributable to Gunbower and Koondrook-Perricoota is estimated at $21.7 million. Around 72% of total consumption expenditure is again attributable to Gunbower National Park.

Asset valuation

The ecosystem asset valuation modelled the monetary value of the opening and closing stocks of all ecosystem assets within the GKP ecosystem accounting area. Use and non-use values were analysed separately. The use and non-use value assessments included a sensitivity analysis on discount rates. Key results are:

- Under a 2.5% discount rate the opening and closing asset valuation for use values were around 3,488 ($NPV millions) and 4,673 ($NPV millions), respectively. The ecosystem services included in this assessment were biomass for timber, biomass for firewood, carbon sequestration and recreation-related services. These are all use values.
- The assessment also demonstrated the different opening and closing non-use values. These were analysed under a discount rate of 2.5%. The opening value was 6,019 ($NPV millions) and the closing value was 4,513 ($NPV millions). This assessment focused solely on the non-use values for ecosystem and species appreciation.

Biodiversity

Biodiversity is relevant across all areas of the ecosystem accounting framework including ecosystem extent, ecosystem condition, ecosystem services and benefits. Direct field-based data on biodiversity can support the compilation of ecosystem condition accounts and may provide input to the measurement of ecosystem services. Further, the information on ecosystem extent and condition can be used to support a basic understanding of the status and trends in biodiversity, across large spatial extents, through the derivation of habitat-based biodiversity indicators.

- The biodiversity assessment considered 10 focal species, as well as changes in community-level diversity for waterbirds and vascular plants.
- For GKP, from 2010 to 2015:
    - the expected persistence of vascular plants increased slightly (from 84.9% to 85.1% of species expected to persist over the long term)
    - mean local species richness of waterbirds decreased slightly (from 17.0 to 16.6 species)
    - the estimated area of suitable habitat for the focal species remained steady (for 3 of the 10 species) or decreased (for 7 of the 10 species).
  - Reductions in diversity for waterbirds and habitat for most focal species from 2010 to 2015 in GKP are likely related to dramatic differences in water availability between these 2 years.
- Comparing the state jurisdictions within GKP, Victoria performed slightly better for waterbirds and the focal species.

Integration and coherence
This project integrated both economic and ecological concepts, models, methods and data. Coherence relies on the integration process and may be limited by the quality of the elements that are being integrated and the approach taken to integration.

A key contribution of this project was to develop coherence between the ecological conceptual models and the core ecosystem accounting framework. An example of the integration that occurred is understanding the link between the concepts of ecosystem states in the dynamic conceptual models of ecosystems (developed for this project) and ecosystem condition as represented in the System of Environmental-Economic Accounting – Ecosystem Accounting (SEEA EA).

The integration of concepts provides the basis for meaningfully integrating and interpreting methods and models from ecological and economic domains. Having a clear line of sight between ecosystem assets and ecosystem services is central to combining environmental and economic information. It is essential to have a common understanding of the characteristics used to classify ecosystem type and measure ecosystem condition and ecosystem services, to ensure coherence of models and methods.

1 Introduction

The Valuing Parks Case Study Project (the Project) is part of the Land and Ecosystem Accounts Project (LEAP), progressing under the national strategy for a common national approach to environmental-economic accounting (IJSC 2018).

The objectives of the Project are to:

- describe the values of the case study sites in accordance with the United Nations (UN) System of Environmental-Economic Accounting – Ecosystem Accounting (SEEA EA) framework (UNCEEA 2021)
- illustrate applicability of ecosystem accounting to support a wide range of decision making
- involve local stakeholder engagement
- generate lessons that can be fed into future ecosystem accounts, including by building and illustrating an operational accounting framework for ecosystems.

The Project delivered a series of ecosystem accounts, covering ecosystem extent and condition, biodiversity, the flow of a set of ecosystem services and the benefits or value (monetary and non-monetary) these services provide. The case study site selected was the Gunbower-Koondrook-Perricoota Forest Icon Site (GKP) (in partnership with the Murray-Darling Basin Authority (MDBA)).

This report is one output of the GKP case study, which was led by the Department of Agriculture, Water and the Environment (DAWE), in partnership with the MDBA; Commonwealth Scientific and Industrial Research Organisation (CSIRO); Department of Industry, Science, Energy and Resources (DISER); GHD; Institute for Development of Environmental-Economic Accounting (IDEEA) Group; and Marsden-Jacob Associates. Other Commonwealth, state and local jurisdictional agencies, private sector entities and academia were involved where relevant.

The case study was implemented collaboratively by several sub-projects (Figure 1).

Figure 2 provides an overview of the suite of reports for GKP. This report is the experimental accounts report and includes a set of ecosystem accounts using account-ready data on ecosystem extent, ecosystem condition, ecosystem services, biodiversity and asset valuation, integrated analysis and key findings and next steps including a summary of the limitations of the outputs and recommendations for improvement.

Figure 1 Sub-projects in the Valuing Parks Case Study Project

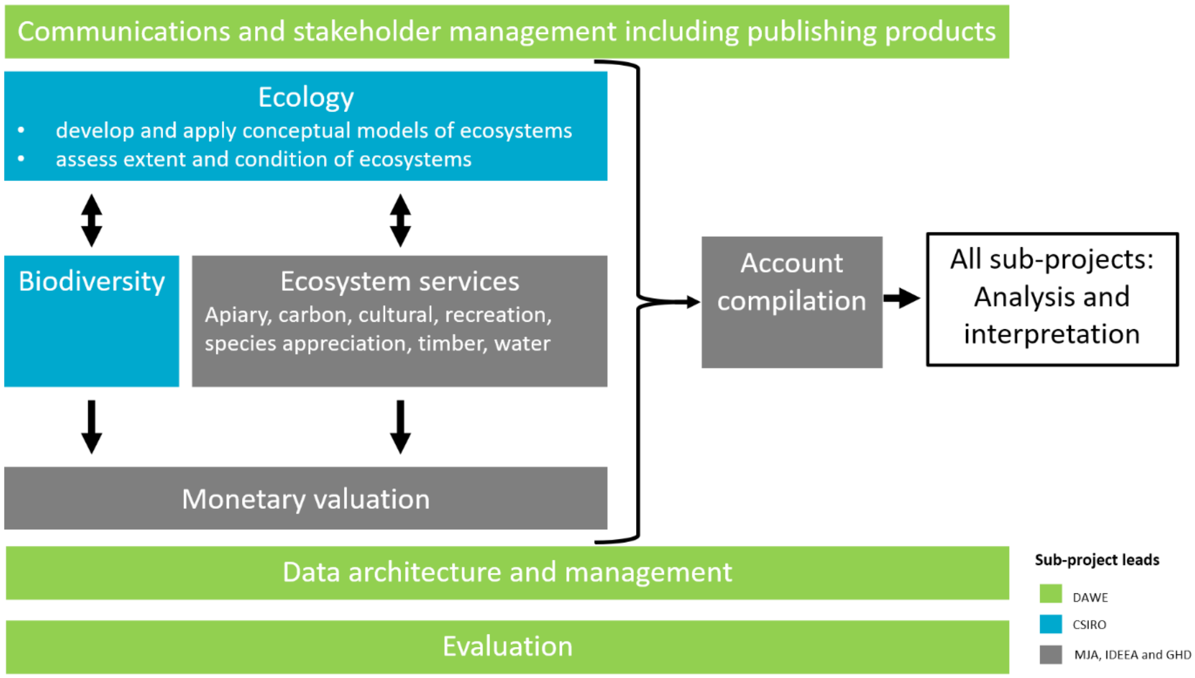
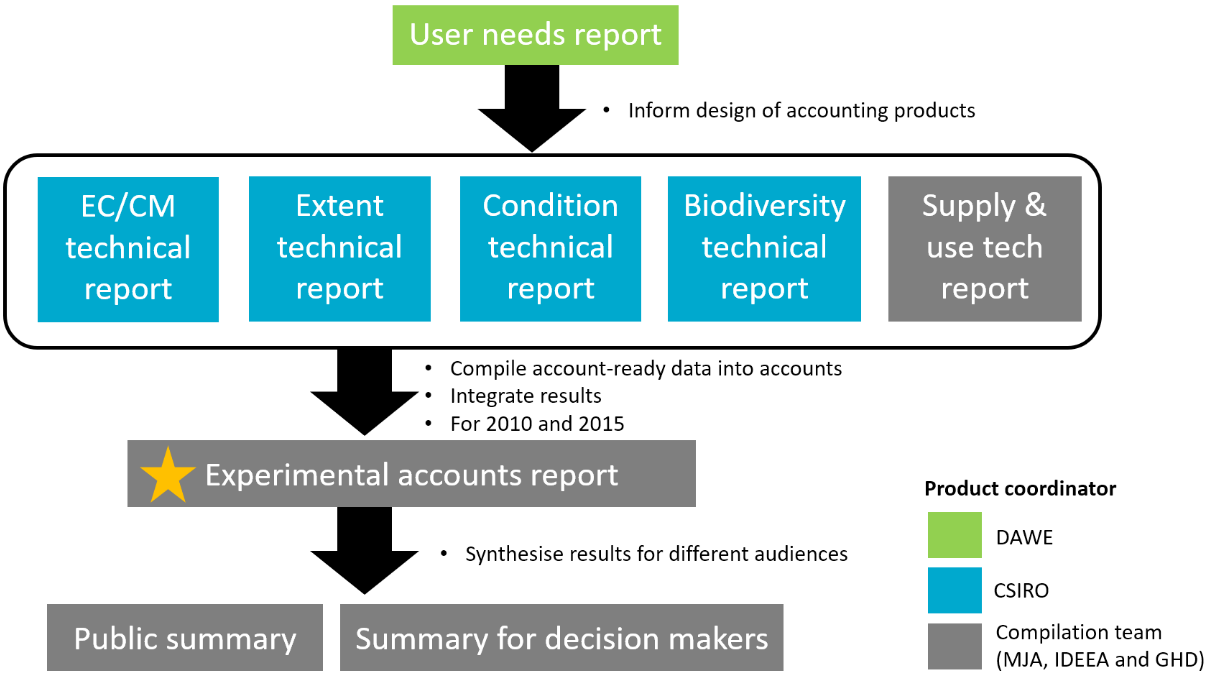


Figure 2 Suite of reports delivered in the Valuing Parks Case Study Project



Note: This report (led by the compilation team) is indicated by an orange star. EC/CM = ecosystem classification and conceptual models.

This report, which has been prepared for DAWE, presents the accounting information compiled during the Project. The report is one of three synthesis reports led by the compilation team:

- *Experimental ecosystem accounts for the Gunbower-Koondrook-Perricoota Forest Icon Site* (this report)

- *Experimental ecosystem accounts for the Gunbower-Koondrook-Perricoota Forest Icon Site: public summary* (McLeod et al. 2021b)
- *Experimental ecosystem accounts for the Gunbower-Koondrook-Perricoota Forest Icon Site: summary for decision makers* (McLeod et al. 2021c).

Detailed methods for each of the accounts and data sources used are provided in the companion technical reports:

- *Assessing condition of ecosystem types at Gunbower-Koondrook-Perricoota Forest Icon Site* (Harwood et al. 2021a)
- *Assessing extent of ecosystem types and condition states at Gunbower-Koondrook-Perricoota Forest Icon Site* (Richards et al. 2021b)
- *Biodiversity in the Gunbower-Koondrook-Perricoota Forest Icon Site and the Murray-Darling Basin* (Mokany et al. 2021a)
- *Ecosystem classification and conceptual models for the Gunbower-Koondrook-Perricoota Forest Icon Site* (Richards et al. 2021c)
- *Technical report on physical and monetary supply and use accounts for the Gunbower-Koondrook-Perricoota Forest Icon Site* (Cheesman et al. 2021).

This report provides a set of information across:

- context (Chapter 2)
- the accounting area (Chapter 3)
- extent (Chapter 4)
- ecosystem condition (Chapter 5)
- ecosystem services (Chapter 6)
- asset valuation (Chapter 7)
- biodiversity (Chapter 8)
- integration, coherence and analysis (Chapter 9)
- key findings (Chapter 10).

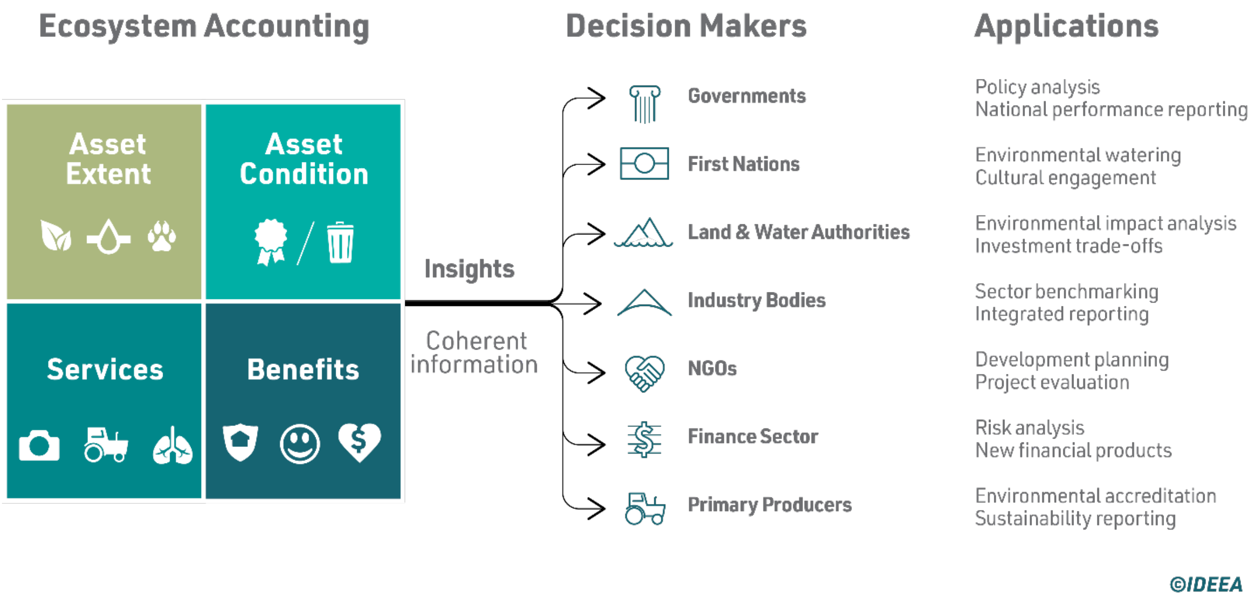
2 Context

2.1 Purpose

The environment's contribution to our prosperity and wellbeing are often overlooked in decision-making by governments, business and the community. Whilst great progress has been made in monitoring and reporting on the environment, existing environmental information is sometimes piecemeal or inconsistent, does not provide sufficient insight into long-term environmental trends and, crucially, is not linked to socioeconomic data or the services and benefits the environment provides. As a result, many decisions do not account for society's dependencies and impacts on the environment including changes in environmental assets over time, and the outcomes associated with these changes (IJSC 2018).

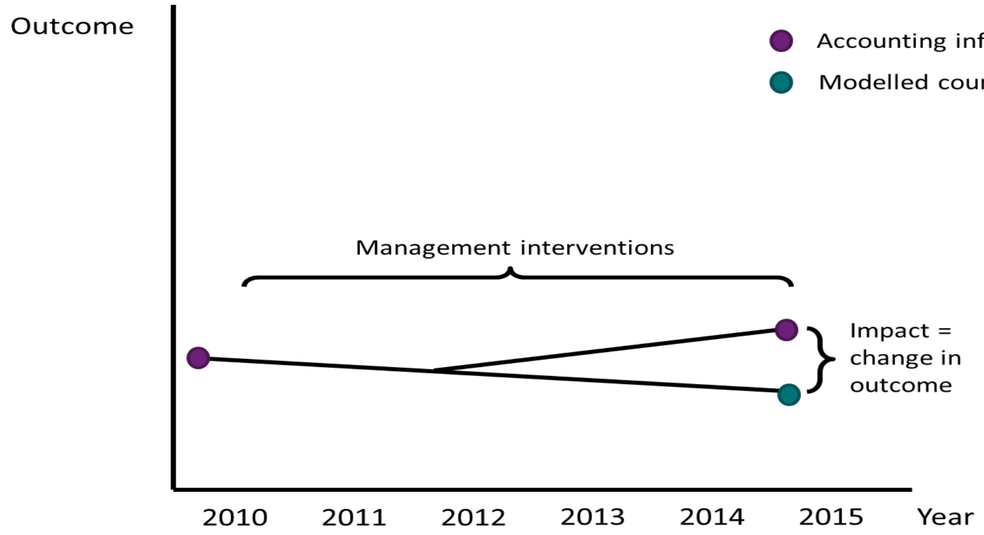
The process of applying the principles of environmental-economic accounting to environmental, economic and social data results in a set of coherent information that can be used to support decision-making. Coherence is defined as the quality or state of cohering: such as a systematic or logical connection or to be logically consistent (Box 20). Users can interpret and analyse coherent information from any of three entry points – environmental, economic and social – to support holistic and comprehensive decision making. Information produced in this nature can underpin a range of applications and be used by many stakeholders (see Figure 3).

Figure 3 Accounting underpins multiple applications



The National Strategy and Action Plan for Environmental-Economic Accounting (IJSC 2018) specifies a set of principles for the development of environmental-economic accounts. These principles note that accounts should be decision-centred and demand-led. The integrated information produced as part of this project is intended for use by the MDBA (and other end users) in their management of the Gunbower-Koondrook-Perricoota Forest Icon Site (GKP). Applications of the information may include the evaluation of the effects of various management interventions (for example, environmental water, weed and pest control) and broader environmental changes (for example, climate change), and supporting the preparation of sustainability reports. Figure 4 provides a stylised view of how this information may be used to assess the outcomes of management interventions through consistent measurement of the state and changes in state (and associated services) in comparison to a modelled counterfactual.

Figure 4 Measuring change in outcomes resulting from management interventions



Note: Assumes counterfactual is consistent with trend before management intervention.

This report describes the accounting information for GKP. It provides quantitative evidence on ecosystem extent, ecosystem condition, ecosystem services and biodiversity for the accounting periods 2010 and 2015. A process for matching the information in the accounting report with the needs of MDBA and broader stakeholders will inform an assessment of the potential to apply environmental-economic accounting across the Murray-Darling Basin. The matching process will also inform institutions about the level of additional analysis or data collection required to support real decisions.

2.2 Why accounting?

A key feature of an accounting approach is the application of standards which enable disparate pieces of information to be integrated in a coherent and repeatable manner. An accounting approach supports the provision of a set of consistent information, enabling temporal and spatial comparisons, aggregation over different geographies to provide a micro and a macro picture, and integration across environmental, social and economic domains. Integration is defined as the act or process of uniting different concepts, methods, models and datasets (Box 20).

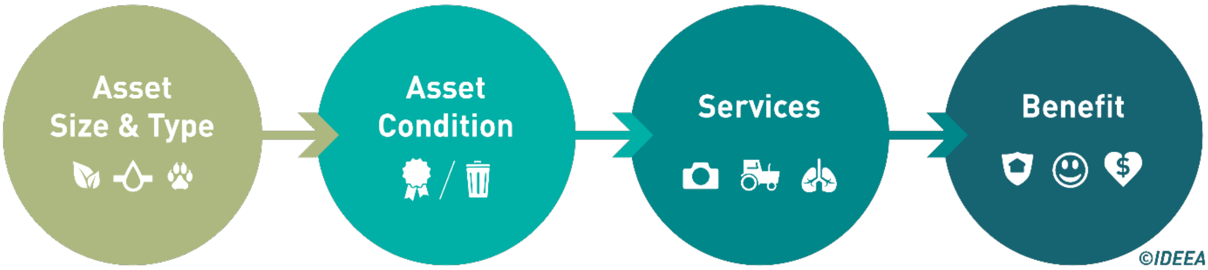
An accounting approach is preferred to an ad hoc approach to data collection as it enables the integration of data, rather than delivering a series of individual and incongruent datasets. The benefits of investing in information as an asset, through initial data collection and ongoing monitoring, increase when said data can be integrated with other datasets.

The information set in this report has been organised according to established environmental–economic accounting principles (UNCEEA 2021). A key aim is to ensure that all information products are coherent. Accounting also generates an information set that is compatible with other sets of information, for example, national accounting information (European Commission et al. 2009).

2.3 The accounting framework

The core ecosystem accounting framework (Figure 5) underpins the presentation of the information in this document (Eigenraam and Obst 2018). The framework presents an approach to bridging ecosystems and the economy by conceptualising ecosystems as an asset. These assets can be differentiated by their type (for example, ecosystem type or further by their specific characteristics) and are then measured according to their quantity (extent or area) and quality (condition). Each ecosystem asset can supply multiple ecosystem services which are, in turn, used in the production of benefits. The flow of services from an ecosystem to a beneficiary (economic units such as households, governments and businesses) is treated as a transaction which can be recorded in physical and monetary units.

Figure 5 Core ecosystem accounting framework



Note: Pressures can also be integrated into the framework to provide another link between the economy/society and the environment.
Source: Eigenraam and Obst (2018)

2.4 Accounting outputs

Several accounts and supplementary tables have been produced as part of the project across a range of different ecological and economic concepts (see Table 1). The stock accounts and supplementary tables include ecosystem extent, ecosystem condition and biodiversity. Flow accounts and supplementary tables focus on ecosystem services including wood provisioning services, climate regulation services, pollination services, recreation related services, ecosystem and species appreciation, waterflow regulation and cultural services. The use of services may be interpreted as a pressure if there are deleterious effects on ecosystems. For example, the extraction of timber greater than sustainable levels may result in a decline in condition and impact the flow of other ecosystem services.

Biodiversity is relevant across all areas of the core ecosystem accounting framework including ecosystem extent, ecosystem condition, ecosystem services and benefits (Figure 37 in Chapter 8). Biodiversity can be analysed at different scales (for example, genetic, species and ecosystem diversity) and spatial configurations. Direct field-based data on biodiversity can support the compilation of ecosystem condition accounts and may provide input to the measurement of ecosystem services. Further, the information on ecosystem extent and condition can be used to support a basic understanding of the status and trends in biodiversity, across large spatial extents, through the derivation of habitat-based biodiversity indicators.

Accounts were developed based on the core ecosystem accounting framework (Figure 5). The workflow (see Appendix) aimed to:

- use the ecosystem characteristics defined in the conceptual models of the ecosystems (Richards et al. 2021c; Prober et al. 2021)
- consistently use the same data, as much as possible, across all accounts
- report all results by ecosystem type, and some by ecosystem state or ecosystem expression (defined in Box 1) as relevant or meaningful (Richards et al. 2021b) .

The accounting outputs represent an integrated assessment of the environment and the economy in GKP. The ecosystem assets assessed in this project (in terms of their extent and condition) are within the boundary of GKP. The scope of the services varies depending on the nature of the service and whether the beneficiaries are in situ (within GKP) or not (for example, global populations benefit from climate regulation services or downstream users benefiting from water flow regulation services).

Table 1 Overview of information produced as part of an accounting approach

Stock accounts: ecosystem assets	Flow accounts: ecosystem services
• Ecosystem extent • Ecosystem condition • Biodiversity	• Wood provisioning services • Climate regulation services • Pollination services • Recreation related services • Water flow regulation • Ecosystem services and First Nations Australians • Ecosystem and species appreciation

Notes:
1. While biodiversity can be considered a characteristic of ecosystem condition, it is also recognised in SEEA EA as a separate thematic account, therefore it is listed here as a separate set of information on the ecosystem assets.
2. Ecosystem and species appreciation are flows concerning non-use values and in SEEA EA are not treated as ecosystem services. They have been included here to recognise the relevance of non-use values in decision making.

Table 2 shows the components and subcomponents of the accounting products developed for GKP. The subcomponents have a measurement unit, temporal coverage, and spatial coverage. Land cover datasets underpin the ecosystem classification of the accounting products and determine the temporal coverage of the inputs used (Appendix B in Richards et al. 2021b; GA 2020). The land cover datasets have a temporal coverage of 2010 and 2015 and as a result, the data relied on for this analysis also has a temporal coverage of 2010 and 2015. Information is provided to the user on the spatial measurement approach so they can understand spatial variability and uncertainty.

Table 2 Overview of accounting products for GKP

Component	Subcomponent	Measurement units	Spatial measurement approach	Temporal coverage
Ecosystem extent	Ecosystem type	Area (ha)	Rules-based interpretation of land cover datasets and other remotely sensed datasets, site-specific datasets, and expert-elicited data (Richards et al. 2021b)	2010 and 2015
	Ecosystem state	Area (ha)	Rules-based interpretation of land cover datasets and other remotely sensed datasets, site-specific datasets, and expert-elicited data (Richards et al. 2021b)	2010 and 2015
	Ecosystem expression	Area (ha)	Rules-based interpretation of land cover datasets and other remotely sensed datasets, site-specific datasets, and expert-elicited data (Richards et al. 2021b)	2010 and 2015
Other extent	Land use	Area (ha)	None – processing done by data custodian State of Victoria (Agriculture Victoria 2021) State Government of NSW and Department of Planning, Industry and Environment, 2017	2014 – Vic 2017 – NSW
	Forest management areas	Area (ha)	None – processing done by data custodian (Sandiford 2021 (DJPR)) (Eastaugh 2021 (ForestCorp NSW (FCNSW))	2010 and 2015
	Apiary management areas	Area (ha)	Victoria – Apiary license location. sourced from DATAVIC. Licence extent drawn using defined radius boundary (State of Victoria (Department of Environment, Land, Water and Planning), 2019)	2010 and 2015
	CAPAD protected areas	Area (ha)	None – processing done by data custodian Commonwealth of Australia (2010)	2010

Component	Subcomponent	Measurement units	Spatial measurement approach	Temporal coverage
Ecosystem condition	Ecosystem condition variable	Range of variables with different measurement units	Extent of ecosystem states combined with land cover classes, remotely sensed datasets and expert-elicited datasets (Richards et al. 2021b; Prober et al. 2021)	2010 and 2015
	Ecosystem condition index	Normalised index (from 0 to 1)	Condition of each ecosystem state assessed by combining expert-elicited condition score (Appendix D of Harwood et al. 2021a) with Habitat Condition Assessment System (HCAS) score (Williams et al. 2021) to result in an index (Harwood et al., 2021a)	2010 and 2015
Ecosystem services	Wood provisioning services	Tonnes and timber grade	Timber harvest areas defined by (Sandiford 2021 (DJPR)), (Eastaugh 2021 (FCNSW)). Harvest data provided by Vicforests (VF) and FCNSW	2010 and 2015
	Climate regulation services	Tonnes carbon per ecosystem type (stock, sequestered)	FullCAM assessment data points manually defined by GHD for all terrestrial ecosystem types. Points distributed geographically across ecosystem types Wetlands based on 2010 and 2015 ecosystem extent.	2010 and 2015
	Floral Resources for Honey	Not applicable No honey production from GKP	Victoria – Apiary license location. (State of Victoria (Department of Environment Land Water and Planning), 2019). Licence extent drawn using defined radius boundary. DPI NSW apiary licence locations	2010 and 2015
	Pollination services	Not applicable, this is a qualitative assessment.	Area of pollination services defined by ecosystem extent for ecosystem type	2010 and 2015
	Recreation related services	Number of visitor days	Survey	2010 and 2015

Component	Subcomponent	Measurement units	Spatial measurement approach	Temporal coverage
	Ecosystem and species appreciation	Species potential habitat by habitat type	Areas of habitat modelled to support 8 focal species (Mokany et al. 2021) (as subset all species) in GKP. Areas of ecosystem type (Richards et al. 2021a) modelled to support two or more species	2010 and 2015
	Water flow regulation	Not applicable	Not applicable	2010 and 2015
	Cultural services	Not applicable. This is a qualitative discussion of how Traditional Owner values are included in accounts.	Not applicable	Not applicable
Biodiversity	Community-level biodiversity: vascular plants	Expected species persistence (%)	Habitat condition (using HCAS (Williams et al. 2021)) and modelled biodiversity patterns (species richness and assemblage similarity) (Mokany et al. 2021a)	2010 and 2015
	Community-level biodiversity: waterbirds	Average number of species	Habitat condition (using Water Observations from Space (WOfS) (Mueller et al. 2016) and modelled biodiversity patterns (species richness) (Mokany et al. 2021a)	2010 and 2015
	Species-level biodiversity: 10 focal species	Area of suitable habitat (ha)	Suitable habitat (using land cover dataset (GA 2020) and species habitat requirements) and biodiversity patterns from SNES dataset (potential extent of occurrence) (Mokany et al. 2021a)	2010 and 2015

Notes:

1. Ecosystem states and expressions reflect a combination of extent and condition of the ecosystem, which is difficult to disentangle. The extent of states and expressions are reported in Chapter 4 on extent accounting, whereas the condition variables and index for these states and expressions are reported in Chapter 5 on condition accounting.
2. Refer to relevant sections of this report for more information on the accounting tables and supplementary tables.
3. The technical reports provide additional information on the data and the transformations applied.
4. The temporal reporting of the data was not always aligned to the accounting period so adjustments have been made.

2.5 Interpretation of accounting outputs

The accounts and supplementary tables presented in this document are a mix of static information, time series information, and more conventional SEEA accounts such as asset accounts with opening and closing balances. Table 3 and Table 4 are examples of asset accounts and supply and use tables for ecosystem services, respectively.

Table 3 Asset account example

Extent	Ecosystem type A	Ecosystem type B	Total (ha)
Opening extent	100	200	300
Additions to extent			
Managed expansion	1	23	24
Unmanaged expansion	3	5	8
Unclassified expansion	–	–	–
Total additions	4	28	32
Reductions in extent			
Managed reduction	1	4	3
Unmanaged reduction	41	6	9
Unclassified reduction	–	–	–
Total reductions	42	10	12
Net change in extent	-38	18	20
Closing extent	62	218	320

Note: This is a stylised example based on Table 4.1 in the SEEA EA framework (UNCEEA 2021). '–' = 0

Table 4 Supply and use accounts example

Ecosystem service	Units	Industry	Household	Government	Ecosystem type A	Ecosystem type B	Ecosystem type C
Supply							
Service A	kg	No value	No value	No value	1	2	12
Service B	tonnes	No value	No value	No value	–	–	–
Total	kg	No value	No value	No value	1	2	12
Use							
Service A	kg	3	12	–	No value	No value	No value
Service B	tonnes	–	–	–	No value	No value	No value
Total	kg	3	12	–	No value	No value	No value

Note: This is a stylised example based on Table 7.5 in the SEEA EA framework (UNCEEA 2021). '–' = 0

Table 5 links some of the policy and decision-making challenges to accounting information. There are many potential applications of coherent accounting information across the decision-making process including problem diagnosis, forecasting, target setting, scenario analysis, monitoring and reporting, and impact evaluation. The suitability of the accounting products to different applications will largely depend on the availability of fit-for-purpose data.

The accounts (stock and flow accounts, supply and use tables) are one of the outputs that can be used in decision making. In many cases, analyses can be performed on the account-ready data that underpins the accounts. Auxiliary information can also be used to further interpret the accounts. An understanding of the applications required to inform decision making, and the need for a set of coherent information (in the form of accounts, tables and account-ready data), can be used to direct the collection of data. This is referred to as demand pull for data rather than supply push for data. The latter generally lacks a clear connection to decision making and is motivated more by those producing data.

Table 5 Linking decision making to accounting information

Decision element	Description	Accounting information application
Problem diagnosis	Quantify trends in physical and environmental state and build business case for policy intervention	Interpret accounting information to assist with diagnosis
Problem diagnosis	Understand how a problem may manifest in the future, building additional evidence for action	Forecast based on accounting information: forecast outcomes associated with business-as-usual scenario
Design solution	Set target to help guide policy	Identify a practical target by considering accounting information
Design solution	Understand the influence of specific drivers in problems (for example, to identify which policy levers will be most influential in solving the problem)	Use accounting information as inputs to scenario analysis to estimate outcomes associated with different actions (for example, business as usual or interventions)
		Use accounting information to estimate the relative efficiency of alternative solutions for example, trade-offs between economic benefits of planned urban development versus degradation of ecosystems or loss of biodiversity that may result
Design solution	Establish relationships between key variables	Use consistent accounting information combined with statistical techniques to establish relationships (for example, increased temperature affects ecosystem health which affects yield)
Evaluate success of solution	For reporting purposes (for example, to demonstrate progress in solving the problem along a time series)	Use accounting information to monitor performance against projected outcomes
		Use accounting information for evaluation of performance against targets (for example, to demonstrate progress against a target and/or attribute influence of policy)
Evaluate success of solution	Understand the effectiveness and efficiency of different investments across the landscape	Use accounting information to demonstrate return on investment
		Use consistent accounting information to underpin quasi-experimental approaches to evaluate impacts

An example of the types of policy questions that can be explored using accounting information is provided in Table 6. There is a risk that Table 6 implies a one-to-one association between an accounting component and policy questions, whether they are basic or complex. Individual elements of the accounting system should be coherent, and they should be readily joined together to support integrated analysis. Information needs to be appropriately designed and collected for it to be useful for this purpose. Data collection should consider multiple policy applications (where appropriate) and standards should be developed to ensure interoperability with future datasets. The return on investment in information increase when data can be used across multiple policy question and decision-making application (for example, scenario analysis or impact evaluation). Data collection cost can be minimised by appropriately designing data collection for multiple uses.

From a policy point of view the coherence of data collection and accounting information allows a decision-maker to link with other policies and coordinate policy responses. Often the information that supports a given policy can only be used for that policy. If there are other related polices it is very difficult to determine how each policy is contributing to the overall objectives. This is particularly true of policies aimed at natural resource sustainability. A simple example is the management of native forests. There is a weeds and pests policy/program, fire management policy/program, timber harvesting policy/program and a recreation and tourism policy/program all of which have different definitions and conceptions of the native forest they are managing. Comparison of the data they collect is difficult and is a barrier to determining which policy/program is more effective and where investment could occur in the future to ensure sustainable outcomes.

Table 6 Linking accounts to policy questions

Account component	Basic policy questions, which can be answered by accounts alone	Complex policy questions, which can be answered by combining accounts with other information or methods
Species-level biodiversity	Have the average numbers of species declined or increased over the accounting period?	How will management actions focused on drivers of change impact future species diversity and distribution?
Ecosystem extent	Have key ecosystems expanded or contracted over the accounting period?	How will management actions focused on drivers of change impact future extent?
Ecosystem condition	Has the health (ecological integrity) of ecosystems improved or declined over the accounting period?	How will management actions focused on drivers of change impact condition?
Physical supply and use	Have ecosystem services to people improved or declined over the accounting period?	What management actions will improve individual ecosystem services?
Monetary supply and use	Has the value of the overall basket of ecosystem services to people improved or declined over the accounting period?	What management actions will optimise the benefits delivered by this ecosystem asset?
Monetary asset values	Has the value of the ecosystem improved or declined over the accounting period?	What is the cost/benefit to the economy and society of the degradation/enhancement of these ecosystem assets?

The approach to the collection of data and coherence described supports a shift in the focus of policy/design from specific interventions to notions of integrated asset management. Asset management is a comprehensive approach to achieve sustainability and long-term productivity while also mitigating climate change risk. An asset-based approach to measurement enables the integration of data from the many entry points to asset management (specific interventions such as weeding, rabbit control, biodiversity protection, watering).

The approach taken in this Project provides one potential solution to collecting and organising information according to an asset management framing. In this Project, the following questions were considered as user needs of the MDBA (DAWE 2021b):

1. How can we quantify the optimisation of economic, social, cultural and environmental outcomes from Basin Plan implementation?

2. How is environmental water helping people?
3. How can we improve the condition of our ecosystems?
4. How can we provide consistent credible information on the social and economic benefits of the MDB Plan?
5. In a very noisy system, how can we disentangle the impact of environmental watering from natural variation?
6. How do we harmonise social, cultural, economic and environmental data and information and fill the resulting knowledge gaps?
7. How do we scale up or replicate information collected at sites to the whole of the MDB so we can manage environmental watering for the whole system rather than at a site level? Can this be done in a way that can accommodate local diversity in environmental, social and economic conditions?

The accounting information and the accounting process have informed question 4, 6 and 7. While this Project has provided important ecological and economic conceptual framing to address the other questions, additional analysis of the accounting outputs and in some cases more local data collection is needed to more fully address them. The accounting tables produced in this document are directly useful for basic policy questions (Table 6) related to problem diagnosis (Table 5), but additional analysis of account-ready data and account tables is needed to understand complex policy questions (Table 6).

Note that the concepts introduced in this section underpin the demonstration of policy-relevant analysis in Section 9 'Integration, coherence and analysis'.

Users of this report will need to carefully match the information from the various tables to the particular policy or operational decision-making needs. This will involve an identification of which account elements are relevant to the questions from decision-makers, based on an understanding of which aspects of the ecosystem asset may be enhanced or degraded as a result of the decision, and whose perspectives and values have 'standing' (i.e. is a key stakeholder) in that decision. Further, if monetary values are going to be used to inform these decisions, the account user must have a working knowledge of the economic elements of the accounts, and in particular the distinctions between use/non-use values, exchange/welfare values and services/benefits.

3 Accounting area

GKP is located on the River Murray north-west of Echuca and covers an area of 56,020 ha across the Victorian and NSW sides of the river (Figure 6). In Victoria, Gunbower Forest (21,066 ha) is part national park (gazetted in 2010 and managed by Parks Victoria) and part state forest (managed by the Victorian Department of Environment, Land, Water and Planning). In NSW, Koondrook-Perricoota Forest (34,954 ha) is made up of several state forests managed by FCNSW. Pollack Swamp is a 200-ha flora and fauna reserve in the north of Koondrook-Perricoota Forest, collaboratively managed by FCNSW and NSW Office of Environment.

Through Ramsar listing of the Gunbower site in 1982, and Koondrook-Perricoota (under the NSW Central Murray Forests Ramsar site) in 2003, and the *Water Act 2007*, the Australian Government also has a stake in management, which can be exercised through the Murray–Darling Basin Authority (MDBA). The Australian Government also has powers under the *Environment Protection and Biodiversity Conservation Act 1999*.

The Gunbower Forest Wetlands site meets 4 of the 9 Ramsar criteria (Hale and Butcher 2011):

- Criterion 1: Gunbower is part of the second largest river red gum forest in the Murray-Darling Basin (the largest being Barmah-Millewa Forest). The size and intact nature of this forested floodplain makes it one of the best representatives of a freshwater, tree-dominated wetland type in the bioregion. Gunbower is also internationally important due to its hydrology as it forms an extensive area of intact floodplain between the River Murray and Gunbower Creek, and is one of few such areas with native vegetation in the bioregion.
- Criterion 2: Five threatened species listed at the national and/or international level have been recorded within the boundary of the Gunbower Forest Ramsar site: Australasian bittern (*Botaurus poiciloptilus*); Murray cod (*Maccullochella peelii*); silver perch (*Bidyanus bidyanus*); river swamp wallaby grass (*Amphibromus fluitans*); and winged peppercress (*Lepidium monoplocoides*).
- Criterion 4: The site meets this criterion based on the role of the site in supporting breeding of wetland birds, frogs, turtles and fish during periods of inundation. A total of 48 species of wetland bird have been recorded breeding within the Gunbower Ramsar site, which is over 70% of the total wetland bird species richness for the site. In addition, there are records of fish spawning in wetland and stream habitats as well as at least two species of turtle and 6 species of frog.
- Criterion 8: The site provides migratory routes for fish between habitat in the River Murray and floodplains, with Gunbower Creek an important passage for native fish. Native fish of the River Murray main channel utilise anabranch and flood runner channels when they are available. Native fish move into off-stream areas on rising flows, and make refuge movements into deeper waters during low-flow periods. Many species spawn on the floodplains. Tagged fish have been recorded moving large distances from the site (up to 300 km upstream and 900 km downstream), which is indicative of pre- and post-spawning behaviour. River red gum forests make a significant contribution to in-stream nutrient accumulation and productivity through litterfall and provide important shelter in the form of coarse woody debris and shaded water.

Koondrook-Perricoota wetlands (which sit within the broader NSW Central Murray Forests Ramsar site) also meet the same 4 Ramsar criteria (Harrington and Hale 2011).

GKP is also one of 6 icon sites that are regularly monitored under The Living Murray (TLM) program, established in 2002 to maintain their ecological health. Icon sites in the TLM program are identified as priority environmental assets in the long-term watering plans developed by Murray-Darling Basin state governments as part of the Basin Plan (MDBA 2018). Under the TLM program, the North Central Catchment Management Authority is responsible for conducting monitoring of environmental assets in Gunbower Forest and coordinating the delivery of environmental water. FCNSW is the Koondrook–Perricoota Icon Site manager, within the TLM program, and coordinates environmental asset monitoring and the delivery of environmental water to Koondrook-Perricoota Forest.

Figure 6 Map of Gunbower-Koondrook-Perricoota Forest Icon Site.

Source: Richards et al. (2021c)

GKP sits within the Murray-Darling Basin. The rivers and wetlands within the Basin have long supported people. Many rivers and wetlands have been modified to provide water for agriculture, towns and industries. Extraction of water from the Basin and modifications to endogenous flow regimes (regulated by climate and Indigenous management) have adversely affected many ecosystems. These modifications include a reduced frequency, magnitude and/or duration of flows, resulting in fewer large overbank flows, and a switch to higher flows in summer and lower flows in winter and spring compared to pre-river regulation (MDBA 2019). These changes have altered the connectivity of rivers to floodplains and to groundwater, with this impacting the health, abundance and range of water-dependent species (MDBA 2019).

In 2012 the Murray-Darling Basin Plan (the Basin Plan; MDBA 2012a) was introduced with the aim of returning the Basin to a healthy working system by improving its environment, while balancing social and economic needs in a sustainable way. The Basin Plan builds on the work started under the TLM and sets out the sustainable diversion limit (maximum quantities of water that can be sustainably taken from the Basin) and environmental water (the share of water that can be used to achieve environmental outcomes). The Basin-wide environmental watering strategy complements the Basin Plan and sets out its long-term environmental objectives (MDBA 2019). These include:

- improve connections along rivers and between rivers and their floodplains
- maintain the extent and improve the condition of native vegetation (river red gum, black box and coolibah forest and woodlands, wetlands)
- maintain current species diversity of waterbirds and improve breeding success and numbers
- maintain current species diversity of fish, extend distributions and improve breeding success and numbers.

Underneath the Basin-wide environmental watering strategy are environmental water management plans for Gunbower Forest (MDBA 2012b) and Koondrook-Perricoota Forest (Hale and SKM 2011). These plans establish priorities for use of environmental water at GKP, setting the ecological objectives and targets and site-specific watering regimes for the two areas, as well as environmental works and water delivery arrangements. An example of environmental works is the Torrumbarry Cutting, which has been constructed as part of TLM works program to deliver water to Koondrook-Perricoota Forest from the Torrumbarry weir pool (Hale and SKM 2011). Ecological objectives in these detailed plans are aligned with those prescribed under the Basin-wide environmental watering strategy.

Environmental watering is helping to sustain the condition of Gunbower Forest, based on a 10-year assessment of TLM monitoring data for GKP against ecological objectives from 2006–07 to 2016–17 (MDBA 2018), which spans the implementation of the Basin Plan and associated environmental watering. However, the absence of larger floodplain watering events (and minimal environmental water delivery) at Koondrook-Perricoota Forest has meant that most ecological objectives have not been met over the 10-year period (MDBA 2018).

TLM monitoring data collected at GKP include:

- stand condition monitoring of communities dominated by *Eucalyptus camaldulensis* (river red gum) and *E. largiflorens* (black box) (for example, Bennetts and Jolly 2017)

- aerial waterbird surveys (for example, Bino et al. 2014)
- fish surveys (for example, Bloink et al. 2018)
- wetland and understorey plant richness and abundance (for example, Bennetts 2014b)
- woodland bird surveys (for example, Webster 2017; Webster 2018)
- water quality monitoring (G. Smith, pers. comm).

4 Extent accounting

4.1 Introduction

Extent accounting records the size and distribution of ecosystems in terms of spatial area (UNCEEA 2021). Extent accounting also records spatial information that is relevant to characterising ecosystems including land use, management areas and protected areas.

Extent accounting highlights:

- the composition of different classes within the accounting area, including relative abundance and scarcity
- trends in extent, including changes in composition and substitution between different ecosystem types
- the relationship between different spatial areas within the accounting area, for example ecosystem extent and land use.

4.2 Method

Account-ready data produced by the ecology sub-project was used to account for ecosystem extent (Richards et al. 2021a). Dynamic conceptual models, expert knowledge and many input datasets were used to produce the account-ready data. A summary of the approach is provided in Box 1. The complete method, including a description of input datasets, is presented in Richards et al. (2021b). A number of datasets were used when accounting for land use and management areas. These datasets are referenced at the bottom of tables and figures.

Box 1 Approach to producing account-ready data for ecosystem extent

- The Australian Ecosystem Models (AusEcoModels) Framework (Richards et al. 2020) was used by experts to create a set of dynamic conceptual models of ecosystems in GKP (Richards et al. 2021c). The AusEcoModels Framework articulates an understanding of ecosystem dynamics under a set of endogenous or reference disturbance regimes ('natural' events such as fire or floods) for different ecosystem types across the Australian continent.
- The dynamic conceptual models were used to develop a classification of ecosystem types, states and expressions for GKP, and a set of rules to assess the spatial extent of these classes based on a range of ecosystem characteristics.
- Ecosystem types in the AusEcoModels Framework are consistent with the SEEA EA reference classification (Keith et al. 2020; UNCEEA 2021), where they are defined as 'reflect[ing] a distinct set of abiotic and biotic components and their interactions'.
- A given ecosystem type can be in a (i) reference state (a dynamic state of an ecosystem that has ecological integrity and is in reference condition) or a (ii) modified state (a dynamic state that is not in reference condition, due to the influence of exogenous disturbances (recent human actions such as land clearing or fire suppression)).
- Ecosystem states are dynamic and appear as different ecosystem expressions in a given location and time. An ecosystem state may express itself in many ways, but a pixel can only be in one expression at a time. The same expression can be found in different states.

- Appropriate national, MDB and site-specific data were gathered to determine the extent of ecosystem types, states and expressions. The data included remotely sensed information, on-ground monitoring data and expert-elicited data (Richards et al. 2021b).2021b).
- Each pixel was classified by ecosystem type, state and expression, at each accounting time point, by comparing the data to the expert-derived rules captured in the dynamic conceptual models of GKP ecosystems.

Note: The approach is explained in full in the accompanying technical report.
Source: (Richards et al. 2021b)

The method used to produce account-ready data on ecosystem extent is novel. It is the first time that the AusEcoModels Framework, which captures the only nationally comprehensive set of conceptual models of ecosystem dynamics in Australia (Richards et al. 2020) has been used to produce information for use in environmental-economic accounting.

The use of the AusEcoModels Framework and dynamic conceptual models has a number of benefits for ecosystem extent accounting including:

- attribution of changes in ecosystem extent to either managed or unmanaged expansions and reductions in area, where changes occur against a backdrop of endogenous (reference) disturbance regimes and non-linear and threshold ecosystem behaviour
- reduced chance of misclassification of ecosystem type because of an explicit reflection of ecosystem dynamics – this is required for interpretation of remotely sensed information, with increasingly higher levels of temporal and spatial resolution. A structured method to interpret year-to-year variability in remotely sensed information, such as land cover, is needed to ensure appropriate change detection and attribution. For example, without the additional interpretation provided by expressions, changes in ecosystem characteristics due to fire (assumed in this example to be an endogenous disturbance) could be misinterpreted as a transition between different ecosystem types, rather than a change in ecosystem expression within a single ecosystem state and type.
- provision of a clear communication tool for synthesising complex ecological information into a visual product that can be used to communicate ecosystem change and drivers of change to a range of stakeholders
- the potential to use the conceptual models in state and transition simulation models which can be used to predict the future extent of ecosystem states and expressions and, therefore, support assessment of the capacity of ecosystems to deliver ecosystem services, under scenarios of climate change or land use. While future scenarios were not assessed in this project, this is an important avenue of further work.

There are 4 key levels of the ecosystem classification used for extent accounting:

- **umbrella class** – Level 1 in the AusEcoModels Framework is umbrella class, equivalent to biomes in the SEEA EA framework
- **ecosystem type** – which reflects a distinct set of abiotic and biotic components and their interactions (UNCEEA 2021). In the AusEcoModels Framework applied here, an archetype model is a unit of an ecosystem classification defined by the ecosystem characteristics (for example, facets of structure, function, composition) that characterise the reference state for

a given scale of organisation, including discrete disturbance and biomass recovery dynamic (Richards et al. 2020). Archetype models in the AusEcoModels Framework serve as templates for the quantification of ecosystem types (Richards et al. 2021a) which, once defined, may be spatially identified and mapped.

- **ecosystem state** – a relatively stable set of ecosystem expressions linked by pathways of disturbance and biomass recovery. Ecosystem types can be described by multiple ecosystem states (reference and modified).
- **ecosystem expression** – a distinct, recognisable, but transient phase within both the reference state and modified states of ecosystems. An ecosystem expression is a manifestation of an ecosystem state at any point in space or time. Multiple ecosystem expressions capture all possible combinations of abiotic and biotic characteristics of an ecosystem state. An example of a set of ecosystem expressions for a Eucalypt woodland may include (i) an immediate post-fire expression with re-sprouting canopy trees, minimal ground cover and a suite of bird species adapted to open environments; and (ii) another expression characterised by large hollow-bearing trees, a midstorey dominated by shrubs and juvenile *Callitris* trees, and bird species that require long-unburnt habitat for food and shelter.

The mapping of the extent of ecosystem states and ecosystem expressions, in addition to ecosystem types, provides additional information that can be reported when accounting for extent. Accounting tables for ecosystem states and expressions can be informative for managers, as a management response may need to be linked to a particular state or expression (which will have a certain set of characteristics as well as potentially unique flows of ecosystem services).

4.3 Areas for improvement

The approach to identify the ecosystem type, state and expression for each pixel may be limited by the existing data, which was derived from satellite sensors or ground-based monitoring programs. In some cases, these data were not sufficient to easily map ecosystem characteristics that distinguish ecosystem states. This may be improved over time with the development of new remote sensing products.

The rules for local geographic details in the final workflow may need to be refined to improve mapping accuracy before these ecosystem accounts can be used for local decision making and management. In the current extent map, there was a moderate level of correspondence between observed ecosystem states (from The Living Murray long-term monitoring plots and additional field data collected in 2020) and mapped ecosystem states within the 'wetlands' ecosystem type (accuracy of 58%), but only weaker correspondence between states in the 'inland floodplain eucalypt forests and woodlands' ecosystem type (accuracy of 22 to 33%) (Richards et al. 2021b). However, there were limited validation points for the 'lowland streams' ecosystem states. For example, the Gunbower Creek is absent in some parts of the Gunbower Forest in the map of ecosystem types. This may be due to misclassification of pixels that straddle the boundary of the icon site and obstruction of satellite detection of open water by overhanging vegetation. Additional work could be undertaken to increase the number of validation points available across all five ecosystem types, including lowland streams.

Future work could also focus on a sensitivity analysis of the workflow used to map the location of ecosystem expressions. By testing how sensitive the outputs are to the rules created by experts and the interpretation of satellite data, the accuracy and consistency of the ecosystem extent account-ready data could be improved.

4.4 Accounting outputs and analysis

The nested classification of ecosystem types, states and expressions for GKP is provided in Table 7. This is the foundation for the accounting presentations made in this report. Information on extent, condition and services will be presented by ecosystem type, and in some cases by ecosystem state and expression.

Table 7 Ecosystem types, states and expressions in the Gunbower-Koondrook-Perricoota Forest Icon Site

Umbrella class	Ecosystem type	Ecosystem state	Ecosystem expression
Eucalypt woodlands	Inland floodplain eucalypt forests and woodlands	Reference*	Mature floodplain eucalypt forests and woodlands
			Reduced tree canopy with wetland, grassland or chenopod understorey
			Dense seedling eucalypts
			Dense pole-stage eucalypt stands
		Modified: Reduced tree canopy over invaded understorey*	Mature floodplain eucalypt forests and woodlands
			Reduced tree canopy over invaded understorey
			Dense seedling eucalypts with invaded understorey
			Dense pole-stage eucalypt stands
		Modified: Invaded mature floodplain eucalypt forests and woodlands*	Invaded mature floodplain eucalypt forests and woodlands
			Reduced tree canopy over invaded understorey
			Dense seedling eucalypts with invaded understorey
			Dense pole-stage eucalypt stands
		Modified: Halophytic state*	Reduced tree canopy with halophytic and invaded understorey§
			Dense seedling eucalypts with invaded understorey
			Invaded halophytic shrubland

	Re-sprouter temperate and subtropical eucalypt woodlands	Reference	Grey box grassy woodlands
			Grey box shrub-grass woodlands
		Modified: Grey box woodlands with exotic understorey*	Grey box grassy woodlands with exotic understorey
			Grey box shrub-grass woodlands with denuded understorey
Callitris forests and woodlands	Fire-intolerant *Callitris* woodlands	Reference	Sandhill pine woodlands
		Modified: Low-rise sandhill pine woodlands*	Senescent *Allocasuarina* over invaded understorey
		Modified: High-rise sandhill pine woodlands*	Denuded canopy and no understorey strata
Sedgelands, rushlands and herblands	Wetlands	Reference	Permanent wet
			Permanent dry
			Semi-permanent wet
			Semi-permanent dry
			Temporary wet
			Temporary dry
		Modified: High-condition wetlands*	Permanent wet (high-condition)
			Semi-permanent wet (high-condition)
			Temporary wet (high-condition)
			Mudflat (high-condition)
		Modified: Moderate-condition wetlands*	Permanent wet (moderate-condition)
			Semi-permanent wet (moderate-condition)
			Temporary wet (moderate-condition)
			Mudflat (high-condition)
			Mudflat (moderate-condition)
			Dirt
		Modified: Low-condition wetlands*	Wet (low-condition)
			Mudflat (low-condition)
			Dirt
Freshwater aquatic ecosystems	Lowland streams	Reference	River Murray main channel
		Modified: Managed flows*	River Murray main channel
			Irrigation supply channel

Note: Also shown are the umbrella classes under which each ecosystem type sits. Archetype models in the AusEcoModels Framework (Richards et al. 2020) serve as general templates for ecosystem types shown here.
*States that occurred at GKP in 2010 and 2015.
Source: Richards et al. (2021c)

In addition to the 5 ecosystem types in the GKP ecosystem classification (Table 7), some areas were classified as cultivated areas, which occurred mostly on the boundary of the icon site and as small areas within GKP. This ecosystem type did not have defined states or expressions, and was identified by the CSIRO-developed ePaddocks™ product which identifies paddock boundaries across the grain production areas of Australia (Diakogiannis et al. 2020; Waldner and Diakogiannis 2020.

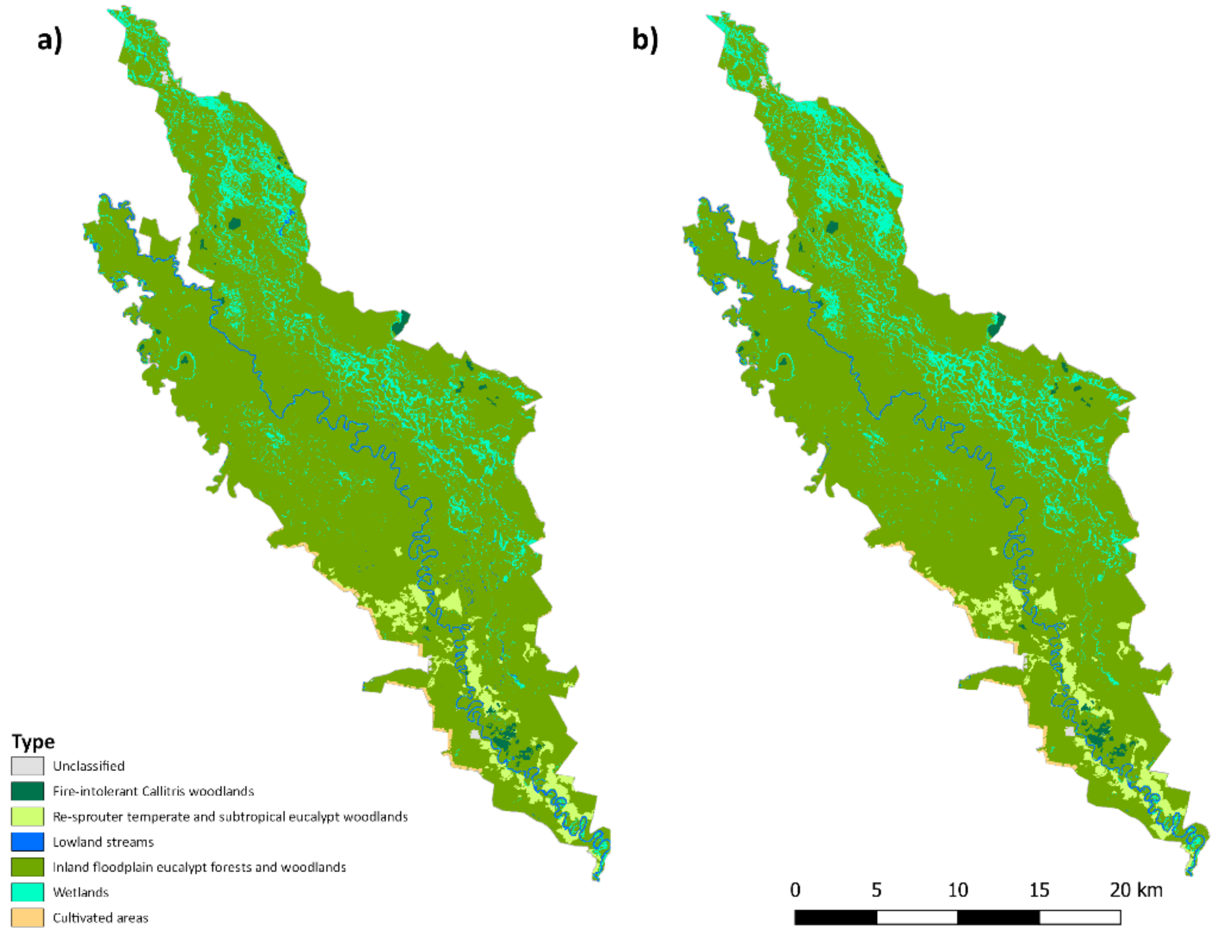
In total, 6 ecosystem types and 1 unclassified class are within the accounting area (see Table 8 for an ecosystem account and Figure 7 for maps of ecosystem extent in 2010 and 2015). 'Inland floodplain eucalypt forests and woodlands' was the dominant ecosystem type in 2010 and 2015 making up approximately 85% of the total area in both years. Wetlands were the second most dominant with a share of approximately 10% in both years. Cultivated areas and fire-intolerant *Callitris* woodlands had the lowest proportion of total area in both years.

Table 8 Ecosystem extent account, by ecosystem type, Gunbower-Perricoota-Koondrook Forest Icon Site, 2010 to 2015

Extent (ha)	Inland floodplain eucalypt forests and woodlands	Re-sprouter temperate and subtropical eucalypt woodlands	Fire-intolerant *Callitris* woodlands	Wetlands	Lowland streams	Cultivated areas	Unclassified	Total
Opening extent (2010)	47,154	1,854	457	4,875	1,125	334	226	56,025
Additions to extent								
Managed expansion	267	–	–	989	58	21	1	1,336
Unmanaged expansion	–	–	–	–	–	–	–	–
Unclassified expansion	1	–	–	–	–	–	–	1
Total expansions	268	–	–	989	58	21	1	1,336
Reductions in extent								
Managed reduction	943	–	–	180	204	3	7	1,336
Unmanaged reduction	–	–	–	–	–	–	–	–
Unclassified reduction	–	–	–	–	–	–	–	1
Total reductions	943	–	–	180	204	3	7	1,336
Net change in extent	–675	–	–	808	–146	18	–6	–
Closing extent (2015)	46,479	1,854	457	5,684	978	352	221	56,025

Note: '–' equates to 0
Source: Richards et al. (2021a, 2021b)

Figure 7 Ecosystem extent by ecosystem type, Gunbower-Perricoota-Koondrook Forest Icon Site, a) 2010 and b) 2015

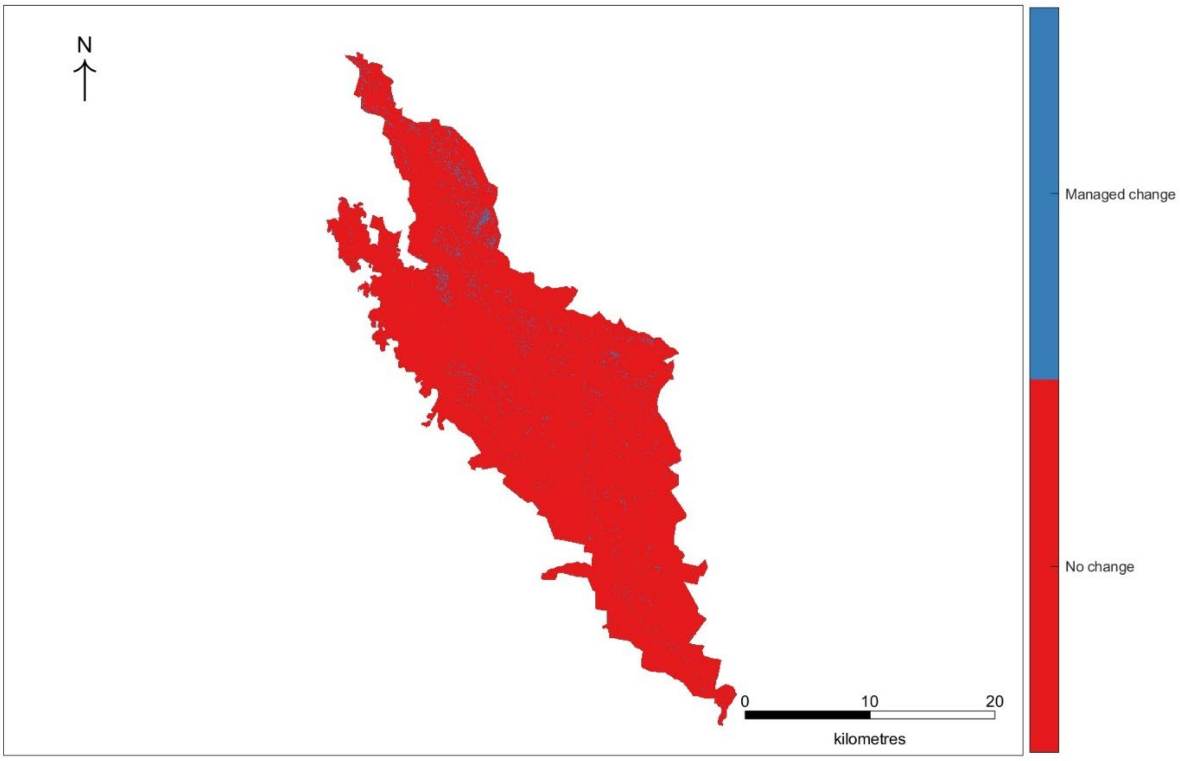


Source: Richards et al. (2021a, 2021b)

Between 2010 and 2015 there were changes in the extent of inland floodplain eucalypt forests and woodlands; wetlands; cultivated areas; and lowland streams. The extent of fire-intolerant *Callitris* woodlands and re-sprouter temperate and subtropical eucalypt woodlands did not change as these areas could not be dynamically mapped from remotely sensed information at this stage. The area of wetlands increased by 808 ha between 2010 and 2015, comprising an expansion of 989 ha and a reduction of 180 ha. The 989 ha increase was dominated by a conversion of 890 ha from inland floodplain eucalypt forests and woodlands. The net increase of 808 ha is approximately 15% of the 2015 extent. The area of inland floodplain eucalypt forests and woodlands decreased by 675 ha between 2010 and 2015, comprising an expansion of 268 ha and a reduction of 943 ha. The net decrease of 675 ha is approximately 1.5% of the 2015 extent.

The area of lowland streams decreased by 146 ha between 2010 and 2015, comprising an expansion of 58 ha and a reduction of 204 ha. The net decrease of 146 ha is approximately 15% of the 2015 extent. Cultivated areas increased by 18 ha between 2010 and 2015, comprising an expansion of 21 ha and a reduction of 3 ha. The net increase of 18 ha is approximately 5% of the 2015 extent. Almost all expansions and reductions in the area were managed (i.e. they were a result of a change in ecosystem state), across all ecosystem types. A map of managed change is shown in Figure 8.

Figure 8 Managed change, Gunbower-Perricoota-Koondrook Forest Icon Site, 2010 to 2015



Source: Richards et al. (2021a, 2021b)

Information on ecosystem extent can be further analysed by different management units. For instance, 63% and 37% of GKP is located in NSW and Victoria, respectively. Table 9 and Table 10 show the ecosystem extent account for GKP by jurisdiction. NSW has a smaller share of GKP as a whole; however it has a higher share of fire-intolerant *Callitris* woodlands and wetlands. Victoria has a higher share of lowland streams and resprouter temperate and subtropical eucalypt woodlands. Shares for unclassified and inland floodplain forests and woodlands are similar in extent across both jurisdictions.

Table 9 Ecosystem extent account, by ecosystem type, Gunbower, 2010 to 2015

Extent (ha)	Inland floodplain eucalypt forests and woodlands	Re-sprouter temperate and subtropical eucalypt woodlands	Fire-intolerant *Callitris* woodlands	Wetlands	Lowland streams	Cultivated areas	Unclassified	Total
Opening extent (2010)	18,632	902	36	523	580	309	86	21,068
Additions to extent								
Managed expansion	165	–	–	58	45	17	1	285
Unmanaged expansion	–	–	–	–	–	–	–	–
Unclassified expansion	–	–	–	–	–	–	–	–
Total expansions	165	–	–	58	45	17	1	285
Reductions in extent								
Managed reduction	78	–	–	131	69	3	4	285
Unmanaged reduction	–	–	–	–	–	–	–	–
Unclassified reduction	–	–	–	–	–	–	–	–
Total reductions	78	–	–	132	69	3	4	285
Net change in extent	87	–	–	−74	−24	14	−3	–
Closing extent (2015)	18,719	902	36	450	556	323	83	21,068

Note: '–' = 0

Source: Richards et al. (2021a, 2021b)

Table 10 Ecosystem extent account, by ecosystem type, Koondrook-Perricoota, 2010 to 2015

Extent (ha)	Inland floodplain eucalypt forests and woodlands	Re-sprouter temperate and subtropical eucalypt woodlands	Fire-intolerant *Callitris* woodlands	Wetlands	Lowland streams	Cultivated areas	Unclassified	Total
Opening extent (2010)	28,523	953	421	4,352	545	24	141	34,957
Additions to extent								
Managed expansion	102	–	–	931	13	5	–	1,051
Unmanaged expansion	–	–	–	–	–	–	–	–
Unclassified expansion	–	–	–	–	–	–	–	–
Total expansions	102	–	–	931	13	5	–	1,051
Reductions in extent								
Managed reduction	864	–	–	49	135	–	3	1,051
Unmanaged reduction	–	–	–	–	–	–	–	–
Unclassified reduction	–	–	–	–	–	–	–	–
Total reductions	864	–	–	49	135	–	3	1,051
Net change in extent	–762	–	–	882	–122	4	–2	–
Closing extent (2015)	27,761	953	421	5,234	422	29	138	34,957

Note: '–' = 0

Source: Richards et al. (2021a, 2021b)

The change in ecosystem type can be analysed further using a change matrix (Table 11). The rows in Table 11 show 2010 ecosystem types, and the columns show 2015 ecosystem types. The extent of ecosystem types that have remained the same between 2010 and 2015 is shown along the diagonal. Reductions in extent by ecosystem type are shown in each row. For example, between 2010 and 2015, 6 ha went from unclassified to cultivated areas. Additions in extent by ecosystem type are shown in each column. For example, between 2010 and 2015 0.1 ha of wetlands went to unclassified.

There were some large changes in ecosystem type (Table 11) between 2010 and 2015. For example, 891 ha of inland floodplain eucalypt forests and woodlands were converted to wetlands, 105 ha of lowland streams were converted to inland floodplain eucalypt forests and woodlands, and 98 ha of lowland streams were converted to wetlands. The changes to the extent of the 'inland floodplain eucalypt forests and woodlands' ecosystem type may reflect uncertainty in the modelling of inundation frequency and duration derived from satellite data rather than real changes. In order to determine the validity of these changes, further work is required, including improvements to inundation modelling and on-ground validation.

Table 11 Ecosystem extent change matrix, by ecosystem type, Gunbower-Perricoota-Koondrook Forest Icon Site, 2010 to 2015

Extent (ha) 2015 Extent (ha) 2010	Inland floodplain eucalypt forests and woodlands	Re-sprouter temperate and subtropical eucalypt woodlands	Fire-intolerant *Callitris* woodlands	Wetlands	Lowland streams	Cultivated areas	Unclassified	Total reductions
Inland floodplain eucalypt forests and woodlands	10,956	–	–	891	36	15	–	943
Re-sprouter temperate and subtropical eucalypt woodlands	–	1,854	–	–	–		–	–
Fire-intolerant *Callitris* woodlands	–	–	457	–	–	–	–	–
Wetlands	–	–	–	4,695	20	–	–	21
Lowland streams	105	–	–	98	921	–	1	204
Cultivated areas	–	–	–	–	–	331	–	–
Unclassified	–	–	–	–	1	6	220	7
Total additions	105	–	–	989	58	21	1	–

Note: '–' = 0

Source: Richards et al. (2021a, 2021b)

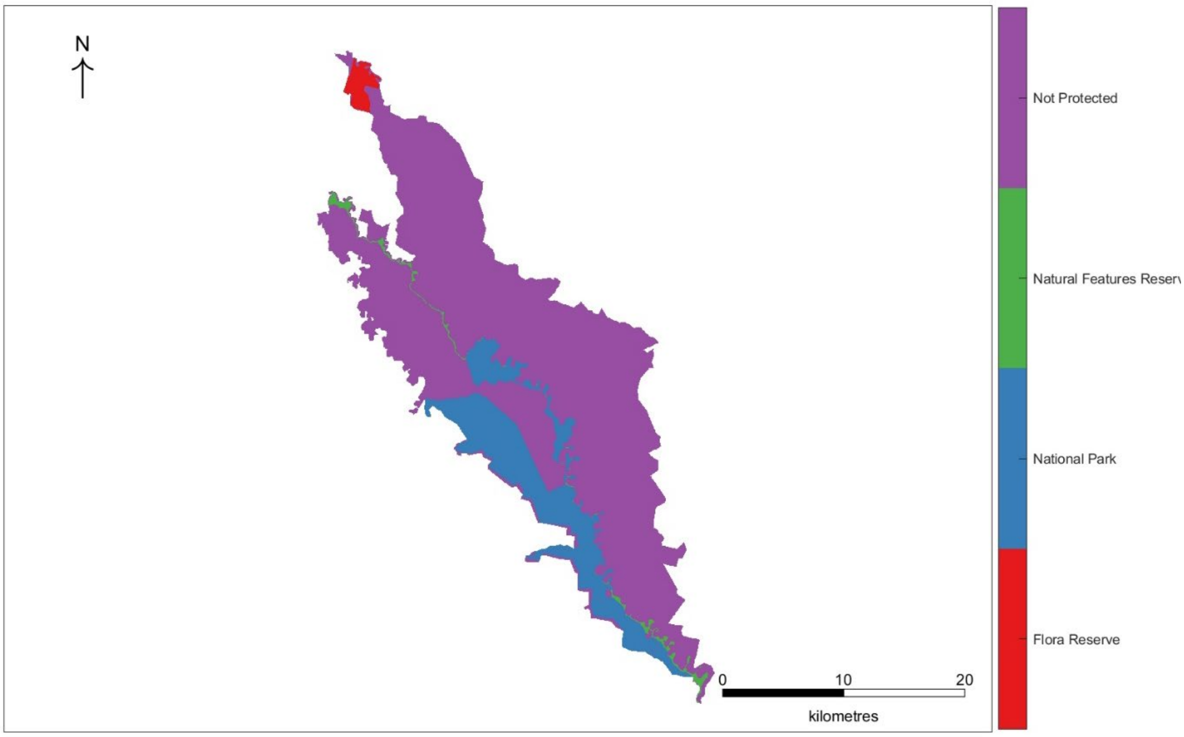
The GKP also comprises a number of different protected areas, including Natural Features Reserves (River Murray Reserve), National Parks (Gunbower) and Flora and Fauna Reserves (Pollack Swamp) (see Figure 9). National Parks cover approximately 20% of the GKP and Natural Features Reserves and Flora and Fauna Reserves cover approximately 1.5% each.

Natural Features Reserve contain inland floodplain eucalypt forests and woodlands and wetlands, resprouter temperate and subtropical eucalypt woodlands and lowland streams. The inland floodplain eucalypt forests and woodlands ecosystem type has the has the largest share of area. There was little change in the extent of ecosystem types between 2010 and 2015.

Flora and Fauna Reserves contain inland floodplain eucalypt forests and woodlands and wetlands (see Figure 9). Inland floodplain eucalypt forests and woodlands have a greater share of the total area than wetlands in both years for these reserves. However, between 2010 and 2015, the area of inland floodplain eucalypt forests and woodlands decreased by 42 ha and the area of wetlands increased by 44 ha.

Gunbower National Park is dominated by inland floodplain eucalypt forests and woodlands, with the ecosystem type making up approximately 90% of the total park area. Re-sprouter temperate and subtropical eucalypt woodlands make up approximately 8%, with the remaining types making up the remainder. There was a net increase in inland floodplain eucalypt forests and woodlands and a net decrease in wetlands between 2010 and 2015 in Gunbower National Park. Lowland streams, which made up 21 ha in 2010, experienced a net decrease of 15 ha between 2010 and 2015.

Figure 9 Protected areas, Gunbower Perricoota-Koondrook Forest Icon Site, 2014



Source: Commonwealth of Australia (2010)

Table 12 Ecosystem extent account, by protected area type, Gunbower Perricoota-Koondrook Forest Icon Site, 2010 to 2015

Extent (ha)	CAPAD area	Flora Reserve								National Park							
	Ecosystem type	Inland floodplain eucalypt forests and woodlands	Re-sprouter temperate and subtropical eucalypt woodlands	Fire-intolerant *Callitris* woodlands	Wetlands	Lowland streams	Cultivated areas	Unclassified	Total	Inland floodplain eucalypt forests and woodlands	Re-sprouter temperate and subtropical eucalypt woodlands	Fire-intolerant *Callitris* woodlands	Wetlands	Lowland streams	Cultivated areas	Unclassified	Total
Opening extent		532	–	–	170	2	–	–	704	8,275	707	7	85	21	3	7	9,105
Additions to extent																	
Managed expansion		4	–	–	47	–	–	–	51	47	–	–	15	1	–	–	63
Unmanaged expansion		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Unclassified expansion		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total additions		4	–	–	47	–	–	–	51	47	–	–	15	1	–	–	63
Reductions in extent																	
Managed reduction		46	–	–	3	2	–	–	51	14	–	–	33	16	–	–	63
Unmanaged reduction		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Unclassified reduction		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total reductions		46	–	–	3	2	–	–	51	14	–	–	33	16	–	–	63
Net change in extent		–42	–	–	44	–2	–	–	–	33	–	–	–18	–15	–	–	–
Closing extent		490	–	–	213	–	–	–	704	8,308	707	7	67	7	3	7	9,105

Note: '–' = 0

Source: Richards et al. (2021a, 2021b), Commonwealth of Australia (2010)

Table 12 (cont)

Extent	CAPAD area / Ecosystem type	Natural Features Reserve: Inland floodplain eucalypt forests and woodlands	Re-sprouter temperate and subtropical eucalypt woodlands	Fire-intolerant *Callitris* woodlands	Wetlands	Lowland streams	Cultivated areas	Unclassified	Total	Not protected: Inland floodplain eucalypt forests and woodlands	Re-sprouter temperate and subtropical eucalypt woodlands	Fire-intolerant *Callitris* woodlands	Wetlands	Lowland streams	Cultivated areas	Unclassified	Total
Opening extent		453	101	–	61	66	–	3	684	37,894	1,046	450	4,560	1,035	330	216	45,532
Additions to extent																	
Managed expansion		6	–	–	5	2	–	–	13	211	–	–	922	54	21	1	1,209
Unmanaged expansion		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Unclassified expansion		–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	1
Total additions		6	–	–	5	2	–	–	13	211	–	–	922	54	21	1	1,210
Reductions in extent																	
Managed reduction		2	–	–	3	8	–	–	13	881	–	–	140	178	3	7	1,209
Unmanaged reduction		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Unclassified reduction		–	–	–	–	–	–	–	–	–	–	–	–		–		1
Total reductions		2	–	–	3	8	–	–	13	881	–	–	141	178	3	7	1,210
Net change in extent		4	–	–	2	–6	–	–	–	–670	–	–	782	–124	18	–6	–
Closing extent		457	101	–	62	60	–	4	684	37,224	1,046	450	5,341	911	349	210	45,532

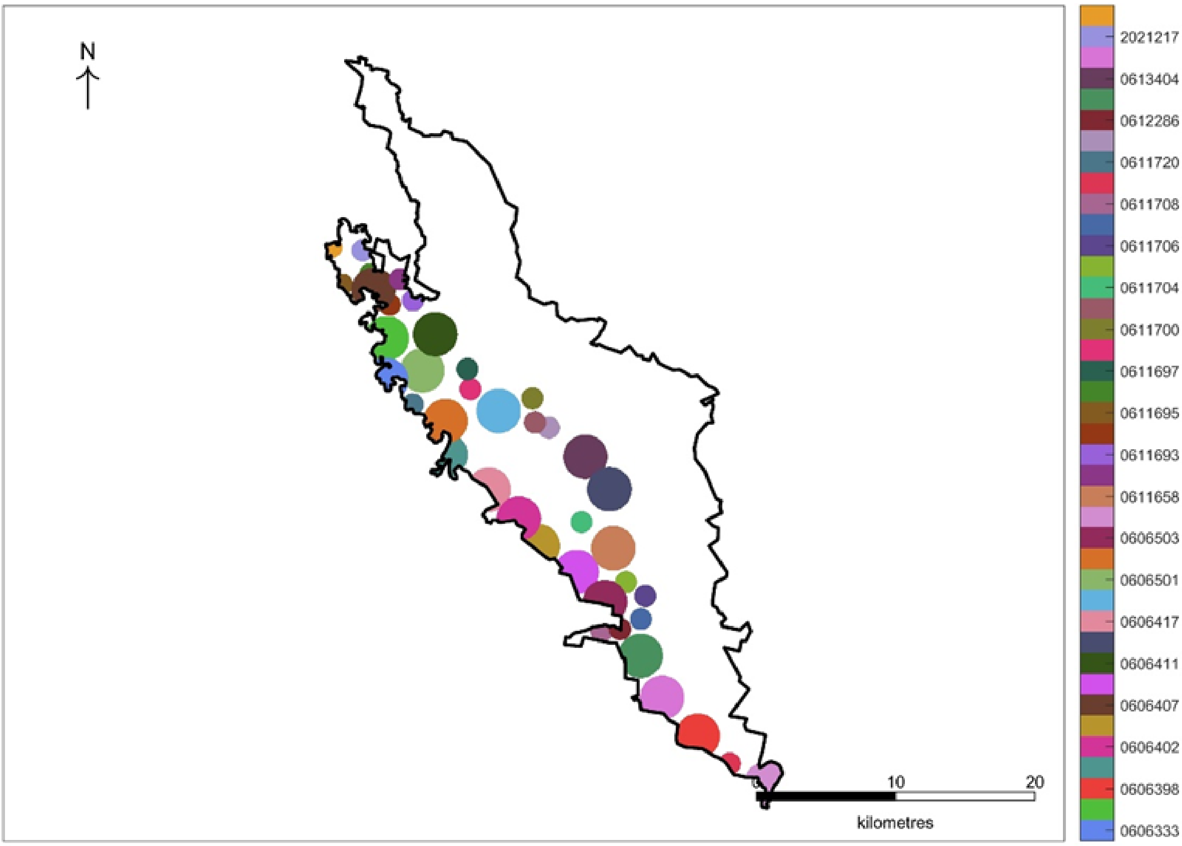
Note: '–' = 0

Source: Richards et al. (2021a, 2021b), Commonwealth of Australia (2010)

There are 40 apiary sites in Victoria. A buffer zone has been defined for each location (800 m for temporary sites, 1600 m for permanent sites) (see Figure 10). The buffer zone is based on licencing information and does not imply the area in which apiary services are provided. This layer includes all apiary licence sites, including Bee farm and Range licences and Temporary Apiary rights, as defined by Crown Land Management. There are a number of sites that may not be recorded in this layer because they do not have a valid 'Tenure-ID' to assign to the site.

The total area of buffered Victorian apiary sites in GKP is 13,448 ha, which is 64% of the Gunbower area in Victoria (note some of the apiary areas extend outside of Gunbower forest and have not been included in the table). The dominant ecosystem type across the apiary sites is inland floodplain eucalypt forests and woodlands which is 85% (11,760 ha) of the total apiary site area (13,448 ha) (see Table 13). Within the 'inland floodplain eucalypt forests and woodlands' ecosystem type, the dominant expressions are 'invaded mature floodplain eucalypt forests and woodlands' expression and 'reduced tree canopy over invaded understorey' expression (see Table 14). This intersection with apiary site buffers identifies dependencies and potential pressures (impacts) on the ecosystems within Victoria.

Figure 10 Victorian apiary buffer zones, 2019



Note: Apiary site IDs are provided in the legend
Source: State of Victoria Department of Environment, Land, Water and Planning (2019)

Table 13 Ecosystem type by apiary site buffer zone, Victoria, 2019

Apiary site ID	Extent of ecosystem type (ha)							
	Inland floodplain eucalypt forests and woodlands	Re-sprouter temperate and subtropical eucalypt woodlands	Fire-intolerant *Callitris* woodlands	Wetlands	Lowland streams	Cultivated areas	Unclassified	Total
606333	325	–	–	12	9	–	2	348
606334	565	–	16	20	14	–	1	616
606398	487	129	–	6	15	–	1	638
606400	340	–	–	3	5	2	2	352
606402	564	4	–	3	–	41	1	612
606403	325	24	–	–	–	34	1	384
606407	506	–	–	20	47	–	3	576
606408	414	149	–	–	–	44	3	611
606411	540	–	–	4	14	–	–	557
606412	447	–	–	4	20	–	–	472
606417	452	–	–	13	–	5	–	470
606427	579	–	–	47	21	–	–	646
606501	649	–	14	35	–	–	–	697
606502	710	–	–	9	7	–	1	727
606503	372	93	7	2	–	36	4	514
606504	95	31	–	38	32	–	2	197
611658	362	113	–	4	27	–	1	507
611692	99	–	–	2	13	–	–	114
611693	145	–	–	2	7	–	–	153
611694	107	–	–	1	–	–	–	108
611695	101	–	–	3	5	–	–	108
611696	31	–	–	–	2	–	1	34
611697	157	–	–	1	7	–	–	165
611698	182	–	–	2	3	–	–	187
611700	97	–	–	1	4	–	–	102
611703	162	–	–	4	9	–	–	174
611704	200	1	–	–	–	–	–	201
611705	82	9	–	1	10	–	–	102
611706	93	6	–	2	12	–	–	113
611707	137	23	–	2	7	–	–	169
611708	125	–	–	–	–	9	1	134
611709	83	37	–	2	6	–	–	128
611720	152	–	–	1	1	1	–	155

Apiary site ID	Extent of ecosystem type (ha)							
	Inland floodplain eucalypt forests and woodlands	Re-sprouter temperate and subtropical eucalypt woodlands	Fire-intolerant *Callitris* woodlands	Wetlands	Lowland streams	Cultivated areas	Unclassified	Total
611721	138	–	–	2	6	–	–	146
612286	124	20	–	–	–	–	11	155
613403	606	10	–	3	15	22	3	659
613404	476	–	–	8	18	–	–	502
2009387	498	72	–	5	7	40	31	652
2021217	141	–	–	5	13	–	1	159
2022741	95	–	–	5	5	–	1	106
Total Apiary	11,760	718	36	272	359	234	69	13,449
Non-Apiary	6,958	184	–	178	197	89	13	7,620
Grand Total	18,719	902	36	450	556	323	83	21,068

Note: Apiary site IDs are provided - A buffer zone has been defined for each site (800m for temporary sites, 1600m for permanent sites) '–' = 0
Source: State of Victoria Department of Environment, Land, Water and Planning (2019)

Table 14 Area (% of total Gunbower area) of apiary sites by ecosystem expression, Victoria, 2015

Ecosystem type	Ecosystem state	Ecosystem expression	Apiary sites	Non-apiary sites	Grand total
Inland floodplain eucalypt forests and woodlands	Reference ('Inland floodplain eucalypt forests and woodlands' ecosystem type)	Dense seedling eucalypts	0.012	0.007	0.019
		Mature floodplain eucalypt forests and woodlands	0.001	–	0.001
	Modified: Invaded mature floodplain eucalypt forests and woodlands	Invaded mature floodplain eucalypt forests and woodlands	15.384	10.486	25.870
	Modified: Reduced tree canopy cover over invaded understorey and Invaded mature floodplain eucalypt forests and woodlands	Combination: 'Reduced tree canopy over invaded understorey' and 'Invaded mature floodplain eucalypt forests and woodlands' expressions	22.940	11.010	33.950
	Modified: Reduced tree canopy over	Dense pole-stage eucalypt stands	1.159	.432	1.590
		Dense seedling eucalypts with invaded understorey	0.012	0.001	0.014

Ecosystem type	Ecosystem state	Ecosystem expression	Apiary sites	Non-apiary sites	Grand total
	invaded understorey	Reduced tree canopy over invaded understorey	13.791	9.692	23.484
	Modified: Halophytic state	Invaded halophytic shrubland	2.521	1.399	3.920
Re-sprouter temperate and subtropical eucalypt woodlands	Modified: Grey box woodlands with exotic understorey	Grey box woodlands with exotic understorey	3.406	0.874	4.280
Fire-intolerant *Callitris* woodlands	Modified: Low-rise sandhill pine woodlands	Senescent Allocasuarina over invaded understorey	0.173	–	0.173
Wetlands	Modified: High-condition wetlands	High-condition wetlands	0.162	–	0.162
	Modified: Moderate and low-condition wetlands	Dirt	0.010	0.001	0.011
		Permanent wet (moderate or low condition)	0.503	0.277	0.780
		Semi-permanent wet (moderate or low condition)	0.545	0.530	1.075
		Temporary wet (moderate or low condition)	0.070	0.035	0.106
Lowland streams	Modified: Managed flows	Managed flows	1.704	0.936	2.640
Cultivated areas	Cultivated areas	Cultivated areas	1.112	0.422	1.534
Unclassified	Unclassified	Unclassified	0.328	0.063	0.392
Total			63.834	36.166	100

Note: % = the % of the total GKP area that lies in the state of Victoria, '–' = 0

Source: State of Victoria Department of Environment, Land, Water and Planning (2019)

Ecosystem types consist of different states (see Table 15). Of the 15 ecosystem states potentially found at GKP (see Table 7), only 11 were found at GKP in 2010 and 2015. Figure 11 shows their spatial distribution. The only reference state found at GKP in 2010 and 2015 belongs to the 'inland floodplain eucalypt forests and woodlands' ecosystem type. Four states (reference states for the 're-sprouter temperate and sub-tropical eucalypt woodlands', 'fire-intolerant *Callitris* woodlands', 'wetlands' and 'lowland streams' ecosystem types) have no recorded extent at GKP between 2010 and 2015.

The area in GKP classified as 'moderate-condition wetlands' modified state was unable to be distinguished from the 'low-condition wetlands' modified states using the available datasets and information, and a combined extent was reported. Similarly, across 50 to 55% of the extent of the 'inland floodplain eucalypt forests and woodlands' ecosystem type, the 'reduced tree canopy over invaded understorey' modified state could not be distinguished from the 'invaded mature eucalypt forests and woodlands' modified state. Hence, a combined extent was reported.

Within the 'inland floodplain eucalypt forests and woodlands' ecosystem type, the modified states dominated the reference state in terms of extent. The reference state was only 3% of the total area of the 'inland floodplain eucalypt forests and woodlands' ecosystem type.

Within the 'fire-intolerant *Callitris* woodlands' ecosystem type, the extent of the 'high-rise sandhill pine woodlands' modified state was greater than the 'low-rise sandhill pine woodlands' modified state. Within the 'wetlands' ecosystem type, 'moderate-condition wetlands' and 'low-condition wetlands' modified states had a greater extent than the 'high-condition wetlands' modified state.

Limited change in the area of ecosystem states and types was observed between 2010 and 2015. For the 'inland floodplain eucalypt forests and woodlands' ecosystem type, there was a 1,282 ha reduction in the area of reference state between 2010 and 2015 and increases in the area of several modified states. These changes may be a result of challenges in classifying pixels using the current workflow where some ecosystem expressions have overlapping characteristics, and/or where key characteristics used to distinguish some ecosystem expressions are related to the abundance of understorey exotic plant species that cannot be detected from satellite sensors. Therefore, while the current changes in ecosystem extent indicate a transition away from the 'inland floodplain eucalypt forests and woodlands' reference state in 2015 after extensive rainfall in the second half of 2010, some of this change may be simply a shift to the 'reduced tree canopy with wetland, grassland or chenopod understorey' ecosystem expression within the reference state, rather than to similar expressions in modified states. This has also been suggested by experts (K. Bennetts, pers. comm.), and it is likely that the reduction in spatial extent of the 'inland floodplain eucalypt forests and woodlands' reference state (as well as the greater than expected extent of the 'halophytic state' modified state) is an artefact, in part, of the challenges associated with interpretation of remotely-sensed imagery.

Table 15 Ecosystem extent account, by ecosystem state, Gunbower-Perricoota-Koondrook Forest Icon Site, 2010 to 2015

Extent (ha) / Ecosystem type	Inland floodplain eucalypt forests and woodlands					Re-sprouter temperate and subtropical eucalypt woodlands	Fire-intolerant *Callitris* woodlands		Wetlands		Lowland streams	Culti-vated areas	Unclass-ified	Total
Ecosystem state	**R**	**M**				**M**	**M**		**M**		**M**	**M**	**M**	
	Reference	**Reduced tree canopy**	**Invaded mature**	**Reduced tree canopy *or* Invaded mature***	**Halophytic state**	**Grey box woodlands**	**Low-rise sandhill pine**	**High-rise sandhill pine**	**High-condition**	**Moderate *or* low condition†**	**Managed flows**	**NA**	**NA**	
Opening extent (2010)	1,288	13,694	4,698	26,005	1,469	1,854	36	421	34	4,841	1,125	334	226	56,025
Additions to extent														
Managed expansion	5	2,448	3,590	2,658	2,522	–	–	–	–	989	58	21	1	12,292
Unmanaged expansion	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Unclassified expansion	1	–	–	–	–	–	–	–	–	–	–	–	–	1
Total expansions	6	2,448	3,590	2,658	2,522	–	–	–	–	989	58	21	1	12,292
Reductions in extent														
Managed reduction	1,288	3,159	1,368	4,936	1,148	–	–	–	–	180	204	3	7	12,292
Unmanaged reduction	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Unclassified reduction	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Total reductions	1,288	3,159	1,368	4,936	1,148	–	–	–	–	180	204	3	7	12,292
Net change in extent	–1,282	–712	2,222	–2,278	1,374	–	–	–	–	808	–146	18	–6	–

Extent (ha)	Ecosystem type	Inland floodplain eucalypt forests and woodlands					Re-sprouter temperate and subtropical eucalypt woodlands	Fire-intolerant *Callitris* woodlands		Wetlands		Lowland streams	Cultivated areas	Unclassified	Total
	Ecosystem state	R	M				M	M		M		M	M	M	
		Reference	Reduced tree canopy	Invaded mature	Reduced tree canopy *or* Invaded mature*	Halophytic state	Grey box woodlands	Low-rise sandhill pine	High-rise sandhill pine	High-condition	Moderate *or* low condition†	Managed flows	NA	NA	
Closing extent (2015)		6	12,983	6,920	23,728	2,843	1,854	36	421	34	5,650	978	352	221	56,025

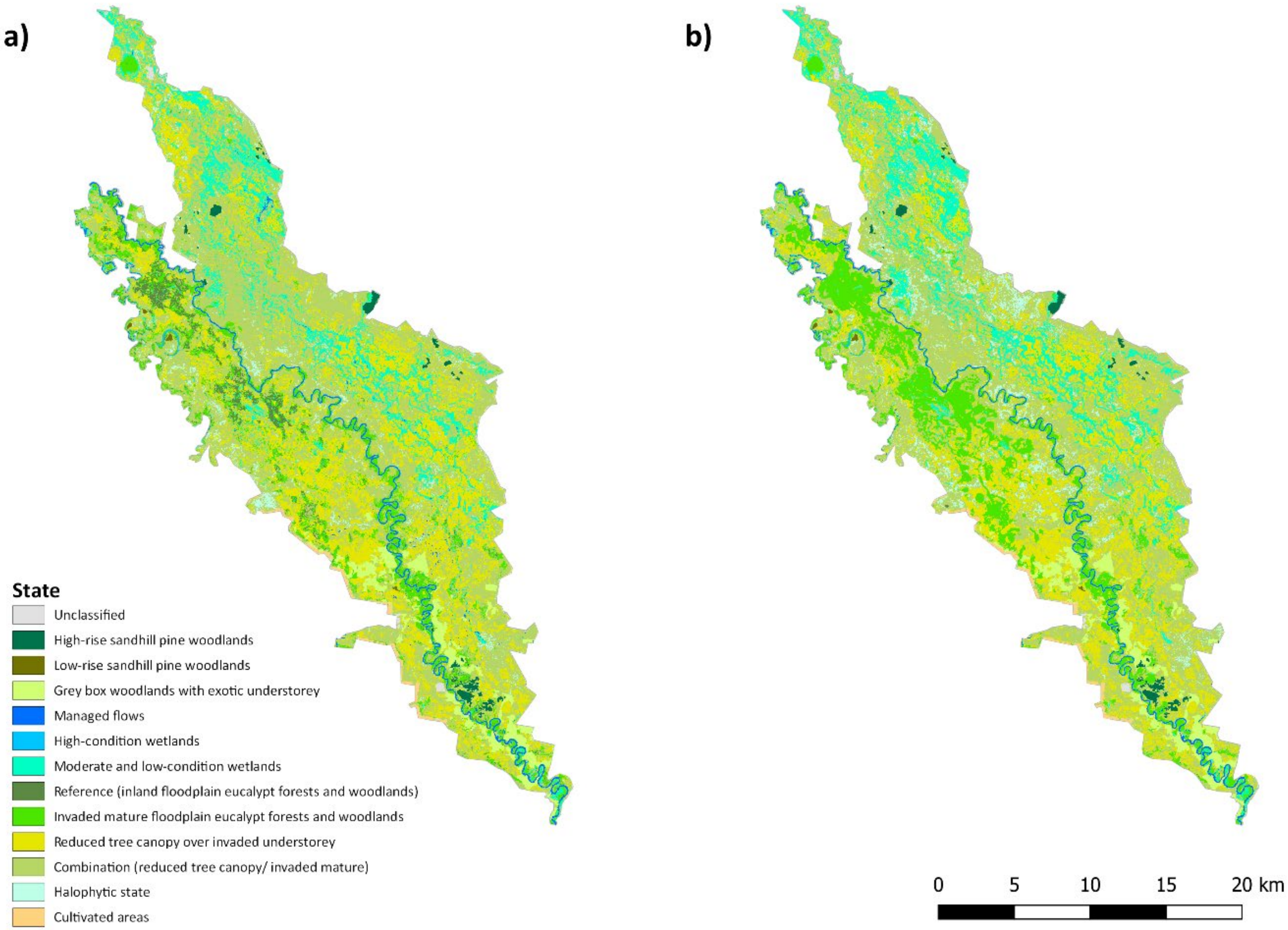
Note: Shortened states names are: Reference = 'Inland floodplain eucalypt forests and woodlands' ecosystem type; Reduced tree canopy = Reduced tree canopy over invaded understorey; Invaded mature = Invaded mature floodplain eucalypt forests and woodlands; Reduced tree canopy and Invaded mature = Reduced tree canopy cover over invaded understorey and Invaded mature floodplain eucalypt forests and woodlands; Halophytic state = Halophytic state; Grey box woodlands = Grey box woodlands with exotic understorey; Low-rise sandhill pine = Low-rise sandhill pine woodlands; High-rise sandhill pine = High-rise sandhill pine woodlands; High-condition = High-condition wetlands; Moderate and low condition = Moderate and low-condition wetlands; Managed flows = Managed flows; Cultivated = Cultivated areas, Unclassified = Unclassified, '–' = 0. R = reference. M = Modified

*In this area, the extent of the 'reduced tree canopy over invaded understorey' modified state could not be distinguished from the extent of the 'invaded mature floodplain eucalypt forests and woodlands' modified state.

†The extent of the 'moderate-condition wetlands' modified state could not be distinguished from the extent of the 'low-condition wetlands' modified state.

Source: Richards et al. (2021a, 2021b)

Figure 11 Ecosystem extent by ecosystem state, Gunbower-Perricoota-Koondrook Forest Icon Site, a) 2010 and b) 2015



Source: Richards et al. (2021a, 2021b)

Accounting for ecosystem expressions can provide an understanding of how endogenous disturbances, for example fires and floods, are affecting ecosystem characteristics. Interpretation of information on the extent of ecosystem expressions could inform management actions. Characteristics at the level of ecosystem expressions are also being used as an input into the quantification of condition (Chapter 5) and ecosystem services (Chapter 6).

Table 66 to 70 (in the Appendix) provide ecosystem extent accounts, by ecosystem expression, for each ecosystem type. For the 'inland floodplain eucalypt forests and woodlands' ecosystem type, large changes are seen between 2010 and 2015 in the 'reduced tree canopy over invaded understorey' expression; 'invaded mature floodplain' expression; combined 'reduced tree cover invaded' and 'invaded mature floodplain' expression; and 'invaded halophytic shrubland' expression. For 'wetlands' ecosystem type, the 'semi-permanent wet (moderate or low condition)' expressions show a large reduction between 2010 and 2015, as does the 'managed flows' expression in the 'lowland streams' ecosystem type. There are either minor or no changes between 2010 and 2015 for other expressions.

Overlaying information on land use can indicate the dependencies and potential pressures on the ecosystems within GKP. Table 16 shows an example of this using a cross-classification of The Victorian Land Use Information System and ecosystem type. National Park land is the dominant land-use class across most ecosystem types in the Victorian part of GKP. Community Service Facilities or Other is the dominant land-use class for lowland streams. Further work is required to validate spatial classifications of each cell to ensure an accurate representation. Table 17 shows a cross-classification of the land-use classes and ecosystem type for the part of GKP that falls within NSW. Production forestry is the dominant land-use class across most ecosystem types. Grazing native vegetation is the dominant class for lowland streams in NSW. In the future, the national land-use dataset (DAWE 2021a) can be used instead of Victorian and NSW land-use data.

Overlaying the extent of ecosystem type with vegetation classes illustrates the degree of alignment with existing data that is used by state/territory governments and other organisations. Table18 shows a cross-classification of the Victorian ccological vegetation classes and the ecosystem types in Victoria. This is not a validation of the extent data, which was instead achieved by comparison with on-ground datasets to determine the accuracy and consistency of the mapped extent of ecosystem types and states (see 'areas for improvement', with further detail in Appendix F of Richards et al. 2021b). These ecological vegetation classes (EVC) were used to map the ecosystem extent and thus this overlay is not an independent check. It also should be noted that we do not expect complete alignment between different vegetation classification schemes and the ecosystem types defined in the AusEcoModels Framework due to the differences in timeframes and in the conceptual framing (the AusEcoModels is based on disturbance and recovery dynamics, rather than plant community composition). For example, the mapping of the extent of ecosystem types, states and expressions uses remotely sensed imagery obtained in 2010 and 2015, compared to static vegetation maps which depict vegetation classes only in the year that the mapping was undertaken.

Table 16 Cross-classification of land use and ecosystem type (% of total), Victoria

Victorian land use classification	Ecosystem type							
	Inland floodplain eucalypt forests and woodlands	Re-sprouter temperate and subtropical eucalypt woodlands	Fire-intolerant *Callitris* woodlands	Wetlands	Lowland streams	Cultivated areas	Unclassifie d	Total
Community Service Facilities or Other	2	–	1	9	61	–	8	2
Detached Home	–	–	–	–	–	–	–	–
Domestic Livestock Grazing	–	–	–	–	–	2	1	–
General Cropping (generally more than 20 ha plantings)	–	–	–	–	–	9	2	–
Livestock Production (Beef Cattle)	–	1	–	1	3	17	25	1
Livestock Production (Dairy Cattle)	1	–	–	–	1	62	39	2
Mixed farming and grazing (generally more than 20 ha)	–	–	–	–	–	5	3	–
National Park - Land	88	60	99	65	14	1	11	84
Nature Reserve	7	31	–	15	14	–	4	9
Outdoor Sports - Extended Areas / Cross Country	–	–	–	–	–	–	–	–
Reserved Land	–	3	–	1	–	–	5	–
Separate House and Curtilage	–	–	–	–	–	–	1	–
State Forest	1	4	–	10	7	–	2	1
Unclassified Private Land	–	–	–	–	–	2	–	–
Vacant Residential Home Site / Surveyed Lot	–	–	–	–	–	–	–	–
Vacant Residential Rural / Rural Lifestyle (0.4 to 20 ha)	–	–	–	–	–	–	–	–
VOID	–	–	–	–	–	–	1	–
Grand total	100	100	100	100	100	100	100	100

Note '–' = 0 land use data is from 2014 and ecosystem extent data is from 2015
Source: State of Victoria (Agriculture Victoria) (2021), Richards et al. (2021a, 2021b)

Table 17 Cross-classification of land use and ecosystem type (% of total), NSW

NSW land use classification	Ecosystem type							
	Inland floodplain eucalypt forests and woodlands	Re-sprouter temperate and subtropical eucalypt woodlands	Fire-intolerant *Callitris* woodlands	Wetlands	Lowland streams	Cultivated areas	Unclassified	Total
1.2.– Managed resource protection	–	–	–	–	–	–	1	–
1.3.– Other minimal use	3	1	–	4	2	1	4	3
2.1.– Grazing native vegetation	3	2	16	4	85	9	33	5
2.2.– Production forestry	94	98	82	92	14	4	22	91
3.2.– Grazing modified pastures	–	–	–	–	–	10	3	–
3.3.– Cropping	–	–	1	–	–	10	26	–
4.3.– Irrigated cropping	–	–	–	–	–	66	10	–
5.4.– Residential and farm infrastructure	–	–	–	–	–	–	1	–
Grand total	100	100	100	100	100	100	100	100

Note '–' = 0. Land use data is from 2017 and ecosystem extent data is from 2015.

Source: State Government of NSW and Department of Planning, Industry and Environment (2017), Richards et al. (2021a, 2021b)

Table18 Cross-classification of ecological vegetation classes and ecosystem type (% of total), Victoria

Ecological vegetation class	Ecosystem type							
	Inland floodplain eucalypt forests and woodlands	Re-sprouter temperate and subtropical eucalypt woodlands	Fire-intolerant *Callitris* woodlands	Wetlands	Lowland streams	Cultivated areas	Unclassified	Total
Floodplain Riparian Woodland	1.06	.11	–	6.36	7.62	–	.91	1.17
Floodway Pond Herbland/Riverine Swamp Forest Complex	9.35	–	–	16.68	–	–	–	8.92
Grassy Riverine Forest	12.13	.31	–	18.85	3.67	–	.36	11.56
Lignum Swampy Woodland	.01	–	–	–	.08	–	–	.01
Plains Grassland	–	.01	–	–	–	–	–	–
Plains Woodland	3.6	91.48	–	.46	.6	.6	27.22	7.44
Riverine Chenopod Woodland	17.98	6.39	1.4	2.82	15.32	93.42	39.38	17.62
Riverine Grassy Woodland	10.16	.17	79.68	11.43	27.74	1.89	7.62	9.94
Riverine Swamp Forest	30.24	.31	–	11.88	9.52	1.15	4.36	28.1
Sedgy Riverine Forest	11.79	.89	2.63	6.5	3.15	.3	7.99	11.04
Sedgy Riverine Forest/Riverine Swamp Forest Complex	1.54	.06	–	3.83	7.02	1.2	6.53	1.57
Semi-arid Woodland	.02	–	16.11	.02	–	1.4	.73	.06
Spike-sedge Wetland	1.3	.24	–	17.78	.24	.05	.18	1.57
Tall Marsh	.54	.03	–	2.77	1.49	–	3.63	.57
Water Body - Fresh	.28	–	.18	.61	23.55	–	1.09	.45
Total	100	100	100	100	100	100	100	100

Note: '–' = 0. EVC data is from 2005 and ecosystem extent data is from 2015.
Source: Richards et al. (2021a, 2021b)

5 Ecosystem condition accounting

5.1 Introduction

Ecosystem condition accounting focusses on the measurement of the quality (ecological integrity) of ecosystems within the accounting area. Condition is assessed with respect to an ecosystem's composition, structure and function, which underpin the ecological integrity of the ecosystem. A reference condition approach is used where ecological integrity is assessed relative to a natural or anthropogenic state depending on the ecosystem. Here, we use a natural reference state. The reference condition is not based on a socially determined or desired state.

Further, the approach to measuring condition in the SEEA EA can be aligned with the concept of intrinsic value. Intrinsic value focusses on measuring ecosystem condition as it relates to ecosystem integrity, independent of what ecosystem services it can provide to humanity.

While not the primary focus in measuring condition, an instrumental value perspective can be supported through the measurement of ecosystem capacity. This entails the reporting of condition variables that are important for key ecosystem services and can be informative for policy-makers. Consistent reporting of condition and capacity supports an assessment of the characteristics that are important in delivering ecosystem services that meet the objectives (for example maximisation of societal welfare) of the asset manager as well as maintaining the ecological integrity of the ecosystem.

Accounting for ecosystem condition builds on the accounting for ecosystem extent and typically consists of three complementary and related information sets:

- Stage 1 – ecosystem condition variable accounting
- Stage 2 – ecosystem condition indicator accounting
- Stage 3 – ecosystem condition indices.

Ecosystem condition accounting can indicate:

- the relative health of an area(s) of an ecosystem type, compared to reference condition (highest level of ecological integrity for that ecosystem type)
- the relative health of an area(s) of an ecosystem type, compared to the health of other ecosystem types (possible because all ecosystem types are measured relative to their own reference condition)
- trends in ecosystem condition, which may be of interest in its own right or may be used to explain changes in ecosystem services
- the distance of ecosystem condition variables from critical ecosystem thresholds.

Ecosystem condition is also an important driver for biodiversity, and thus the account-ready data in this chapter is an input to the biodiversity assessment in Chapter 8.

5.2 Method

Account-ready data produced by the ecology sub-project (Harwood et al. 2021b) was used for ecosystem condition accounting. Account-ready data for ecosystem condition variable accounting was compiled from many sources including expert elicitation, published studies, on-ground monitoring data and remotely sensed datasets (Prober et al. 2021; Richards et al. 2021b, 2021c). The account-ready data for the ecosystem condition index was developed using expert elicitation (Harwood et al. 2021a) and the Habitat Condition Assessment System (Williams et al. 2021). A summary of the approach is provided in Box 2 and the complete method is presented in Harwood et al. (2021a). The data used to populate the accounts are referenced at the bottom of the accounting tables.

Box 2 Approach to producing ecosystem condition account-ready data

- Ecosystem condition variable (stage 1) and ecosystem condition index (stage 3) accounts were compiled. Ecosystem condition indicator (stage 2) accounts were not compiled (as discussed in the text after this box).
- Many sources were used to populate information on ecosystem condition variables including the collation of expert opinion, published literature, remote sensing and monitoring datasets from GKP.
- The variables were chosen based on the dynamic conceptual models of GKP ecosystems (Richards et al. 2021c), developed by experts to represent the ecosystem types, states and expressions and their structure, function, physical and chemical, and composition characteristics. To ensure coherence, we prioritised variables that were used in the Land Cover Classification System used for the land cover dataset (GA 2020) and the potential for the data to be used in ecosystem service estimation.
- An ecosystem condition index was calculated using an approach that combines expert-derived condition scores for ecosystem states, the spatial extent of ecosystem types and states, and remotely derived national condition surfaces from the Habitat Condition Assessment System (HCAS) (Williams et al. 2021).
- Each ecosystem state has a single expert-elicited condition score (constant across time) relative to reference condition, defined as the condition of an ecosystem with the highest level of ecological integrity (Harwood et al. 2021a). Experts were asked to provide an aggregate condition score for each ecosystem state after being shown the condition characteristics and variables, conceptual models and qualitative descriptions for that state and its corresponding reference state.
- The ecosystem condition index was produced by combining the expert-derived condition scores with HCAS scores, which provide temporal and spatial variability in the condition score within the extent of each ecosystem state between 2010 and 2015.
- HCAS is a 250 m resolution national product of habitat condition. It uses Earth observation products, site condition reference data, and information about soils, climate and landform to estimate the condition of terrestrial ecosystems in terms of their predicted capacity to support the species once occurring there naturally.
- The ecosystem condition index was spatially averaged by ecosystem type for reporting in account tables.

Note: The approach is explained in full in the accompanying technical report
Source: Harwood et al. (2021a)

The conceptual framing of HCAS and the AusEcoModels Framework are aligned with each other and are based on conceptual models of ecosystem types and their dynamic ecosystem states (captured as a suite of ecosystem expressions), whose condition is assessed relative to a reference condition with ecological integrity. This approach, which is consistent with the SEEA EA framework, has a number of benefits for condition accounting:

- overcoming a shortcoming of other methods, where changes in ecosystem characteristics may be incorrectly interpreted as changes in condition, rather than dynamics within an ecosystem state driven by endogenous disturbance and biomass recovery processes. Conceptual models that include ecosystem dynamics for both reference and modified states enable this attribution of change. For example, changes in vegetation canopy cover caused by drought may be incorrectly classified as a change in condition when instead these may be endogenous variations in ecosystem characteristics within a state. This interpretation is critical for policy and management considerations where incorrect attribution of a degradation event would impact the calculation of ecosystem service supply and valuation. This could then impact, for example, payments to landholders for ecosystem services or evaluation of policy effectiveness.
- providing a method for explicitly linking changes in ecosystem extent to changes in condition. This is because the extent of ecosystems is described by the extent of 'ecosystem condition states', therefore a change in the area of an ecosystem state directly corresponds to a change in ecosystem condition.
- providing a framework for understanding the drivers of change, including those that cause a transition between ecosystem states, resulting in changes to the ecosystem condition index of ecosystem types, and a method for interpreting this change.

An important overall discussion point is the process by which the account-ready data for ecosystem condition variables and the ecosystem condition index have been produced. The process to aggregate to a stage 3 ecosystem condition index differed from that presented in the SEEA EA framework, where stage 1 variables are converted to stage 2 indicators which are then aggregated to stage 3 condition index. Instead, the stage 3 ecosystem condition index was assessed by combining condition scores from:

- expert elicitation, and
- the HCAS v2.1 dataset based on some stage 1 variables at 250 m resolution in the form of structural cover products derived from MODIS satellite time series, for example, persistent vegetation, recurrent vegetation, non-photosynthetic vegetation and bare ground.

The stage 3 condition method skips the compilation of the stage 2 condition indicators. Nonetheless, scoring of ecosystem condition variables with respect to a reference condition, and aggregation of these indicators, is implicit within the expert elicitation process and the HCAS scores.

Importantly, the alternative method used (going straight from stage 1 to stage 3) supported the quantification of condition for modified ecosystem states where a quantification of reference values of ecosystem characteristics was mostly not possible. For example, the 'grey box grassy woodlands', 'grey box shrub-grass woodlands'' and 'sandhill pine woodlands' expressions represent threatened ecological communities and no examples of these ecosystems exist in reference condition. Therefore, it is not possible to assess the indicators for a stage 2 condition indicator account for states with these expressions.

5.3 Areas for improvement

Future work would ideally assess auxiliary information to verify changes in condition that are detected in this Project.

The method used here for expert elicitation of condition scores for each ecosystem state was a pilot. Future research should undertake further expert elicitation to validate reference sites used, and generate more locally applicable validation and calibration data, implemented with statistical cross-calibration between experts. Methods such as the Habitat Condition Assessment Tool are one potential option for application (White et al. 2019).

The HCAS method was developed to overcome limitations in satellite remote sensing of land cover when used for biodiversity assessment. This data needs to be interpreted correctly in order to estimate the persistence of native species and ecosystems. This interpretation requires consideration of the dynamics and characteristics of ecosystems, over space and time, as has been done in this project, using concepts coherent with AusEcoModels and SEEA EA frameworks. While the resulting HCAS v2.1 dataset provides the current best estimate of habitat condition nationally, additional research could potentially further improve the data and methods (Williams et al. 2021). For example, future work could:

- quantify whole-model uncertainty to provide site-level confidence intervals (for example, via model emulation)
- blend high-resolution low-frequency with lower-resolution high-frequency remote-sensing imagery nationally to extend the spatial resolution of HCAS to 25 m or intermediate levels (for example, 90 to 100 m nationally).

There is also opportunity to develop methods for annual or even more frequent assessment of ecosystem condition, and/or custom products for relevant services.

5.4 Accounting outputs and analysis

A broad set of information on ecosystem characteristics is central to measuring and interpreting condition. This section focusses on presenting information on ecosystem condition variables (stage 1) and an ecosystem condition index (stage 3).

Ecosystem condition variable accounting shows the opening and closing values for selected variables by ecosystem expression. The variables are grouped based on the SEEA EA ecosystem condition typology (see Box 3).

Box 3 The ecosystem condition typology

This hierarchical typology organises data on ecosystem condition characteristics by (i) abiotic ecosystem characteristics on the physical and chemical state, (ii) biotic ecosystem characteristics on the structural, functional and compositional state, and (iii) landscape-level characteristics, describing mosaics of ecosystems at coarse spatial scales.

Ecosystem condition variable accounting shows the information used to identify the ‘condition’ state of an ecosystem and its change over time. Recording ecosystem condition variables also supports analysis of the link between management actions, ecosystems, and ecosystem services and benefits since specific characteristics and variables will link to certain ecosystem services and will be affected by various management actions. Ecosystem condition variable accounting reflects an explicitly neutral approach since each entry is not compared to a baseline, and there is no implied judgement of relative importance.

The following 3 groups of ecosystem condition characteristics were used for both ecosystem extent accounting (Chapter 4) and ecosystem condition variable accounting (in this chapter):

1. Categorical land cover classes from the land cover dataset (GA 2020); these do not change over time for a given type. These classes are identified using a range of ecosystem condition characteristics in a separate process of land accounting (DAWE 2021a).
2. Variable remote sensing data, which change over time within the bounds defined in the conceptual models for the different ecosystem expressions (Richards et al. 2021c). For example, woody cover fraction might be between 2 and 5 in an expression, and in practice this might be 2.5 for 2010 and 3.0 for 2015, spatially averaged over all of the extent of that expression. To obtain these values, the extent of the expressions are intersected with the following datasets described in Richards et al. (2021b):
    a. Water Observations from Space (WOfS)
    b. RiMFiM – modelled flood inundation frequency and duration
    c. water persistence
    d. woody cover fraction
    e. stand condition index
    f. canopy height
    g. canopy cover
    h. above-ground biomass
    i. live basal area index
3. Inferred data (Prober et al. 2021) in cases where spatially complete data (derived from satellite imagery) was not available for some ecosystem condition characteristics. We used the first two groups of characteristics to identify whether a pixel was in a given expression, and then used the conceptual models (the rules in the workflow; Richards et al. 2021c) to logically infer the values for the missing ecosystem condition characteristics. These are ranges in some cases.

Ecosystem condition variable accounts for each ecosystem state and expression are shown in Table 71 to Table 77 (in the Appendix). Categorical classes (group 1) are not shown as these are constant for all states and expressions in an ecosystem type. Inferred data (group 3) and some of the variable remote sensing data are shown. As described in the companion report on the ecosystem classification and conceptual models (Richards et al. 2021c), information on the values of ecosystem condition variables for each ecosystem expression were elicited from experts, recorded from long-term monitoring plots and gathered from the literature. To calculate condition variables for ecosystem states the values were spatially weighted (according to the extent of expressions, see Table 66 to Table 77 in the Appendix).

There are a number of challenges associated with producing and interpreting ecosystem condition variable accounts using the inferred data. Variation between years only comes from changes in the area of expressions, because the value for each expression remains constant and is derived from extrapolation of point-based information from monitoring plots and other sources. Further, there are occurrences of no data for particular variables in certain expressions such that the area-weighted mean value for each ecosystem state may not be based on the characteristics of all expressions within that state. However, using inferred data for ecosystem condition variable accounts enables the inclusion of a large number of characteristics that cannot be detected through more spatially complete methods, such as interpretation of satellite imagery.

The most material changes in the ecosystem condition variable accounts occur in the reference state of the 'inland floodplain eucalypt forests and woodlands' ecosystem type. The large decline in area of mature floodplain between 2010 and 2015 drives the change in the area-weighted mean value for this reference state.

Aggregate ecosystem condition indices can be produced where there is interest in reporting on ecosystem condition at higher levels of aggregation than the ecosystem condition variable or ecosystem condition indicator accounts.

The derivation of ecosystem condition indices within the SEEA EA framework is optional. Nonetheless, ecosystem condition indices are useful to allow interpretation of tables of ecosystem condition variables. There are a variety of ways in which individual characteristics can be weighted to produce an overall index. In the approach here, as described in Box 2, the ecosystem condition index was produced by combining the HCAS condition score and the expert-derived condition scores for each state. For this index, '1' represents reference condition (with the highest possible ecological integrity), and '0' is the furthest distance from reference condition. Changes in the ecosystem condition index over the accounting period arise from changes in the areas of different ecosystem states and their ecosystem condition index.

The stage 3 ecosystem condition index account is presented in Table 19. Maps for 2010 and 2015 are presented in Figure 12 and Figure 13. Table 20 and Table 21 show the ecosystem condition index for Gunbower and Koondrook-Perricoota, respectively.

The ecosystem condition index shows GKP, in general, to be in moderate condition, with aggregated mean scores of 0.498 and 0.481 for 2010 and 2015, respectively (Table 19).

The largest changes in condition were observed in the 'inland eucalypt floodplain forests and woodlands' and 'cultivated areas' ecosystem types. Two ecosystem types, 'wetlands' and 'fire-intolerant *Callitris* woodlands', show no apparent change in ecosystem condition over the period. Both types show minor changes at more decimal places. Changes within the 'fire-intolerant *Callitris* woodlands' ecosystem type are restricted to the 'low-rise sandhill pine woodlands' ecosystem state (Table 23), since the condition for the 'high-rise sandhill pine woodlands' state was taken directly from the atemporal expert scores. No expert-derived condition scores were elicited for the cultivated and unclassified areas at GKP, and the ecosystem condition index for these areas is based solely on the HCAS habitat condition score. Ecological timeframes are long, and major changes in condition are not expected to manifest in 5 years, particularly once noise due to unmanaged (natural) variations has been removed as in our approach. Therefore, it is very likely that in reality there was effectively no change between 2010 and 2015 in GKP, as shown in Table 19.

An alternative presentation of condition information is provided in Table 22. It shows the area in GKP that is covered by various ranges of ecosystem condition index relative to the reference condition. It enables analysis of the changes in area across the condition intervals between years. For example, there was an addition of 6,392 ha and a reduction of 7,629 ha from the interval of 0.40 to 0.50. Care is needed when interpreting this data due to boundary effects – that is, a movement from 0.499 to 0.501 can manifest in a change from one interval from another, but it is a useful way to identify any potential errors in the dataset.

A more ecologically meaningful approach is shown in Table 23, which shows the condition for each ecosystem state. This table shows the result of binning the areas into ecologically meaningful ecosystem states, instead of an arbitrary discretised range of 0.1 as in Table 22. Table 24 offers further detail, showing how varying percentages of areas in each state in 2010 and 2015 contribute to an overall ecosystem condition index for each ecosystem type. The supplementary information on change in extent of expressions (see Table 66 to Table 70 in the Appendix) can provide the additional detail on unmanaged (natural) variations between 2010 and 2015, which can further assist end users in interpreting the information in these condition accounts.

Assessing auxiliary information to verify and attribute changes in condition that are detected in this Project would also aid in understanding and interpreting the high-level ecosystem condition index. A good first step would be to analyse auxiliary information on the drivers for transitions between states (as articulated in the conceptual models of ecosystems, Richards et al. 2021c), and correlate these with the changes in extent and condition seen in these accounts. Additional work to create a change matrix by ecosystem state would also be informative.

Table 19 Ecosystem condition index account, by ecosystem type, Gunbower-Koondrook-Perricoota, 2010 to 2015

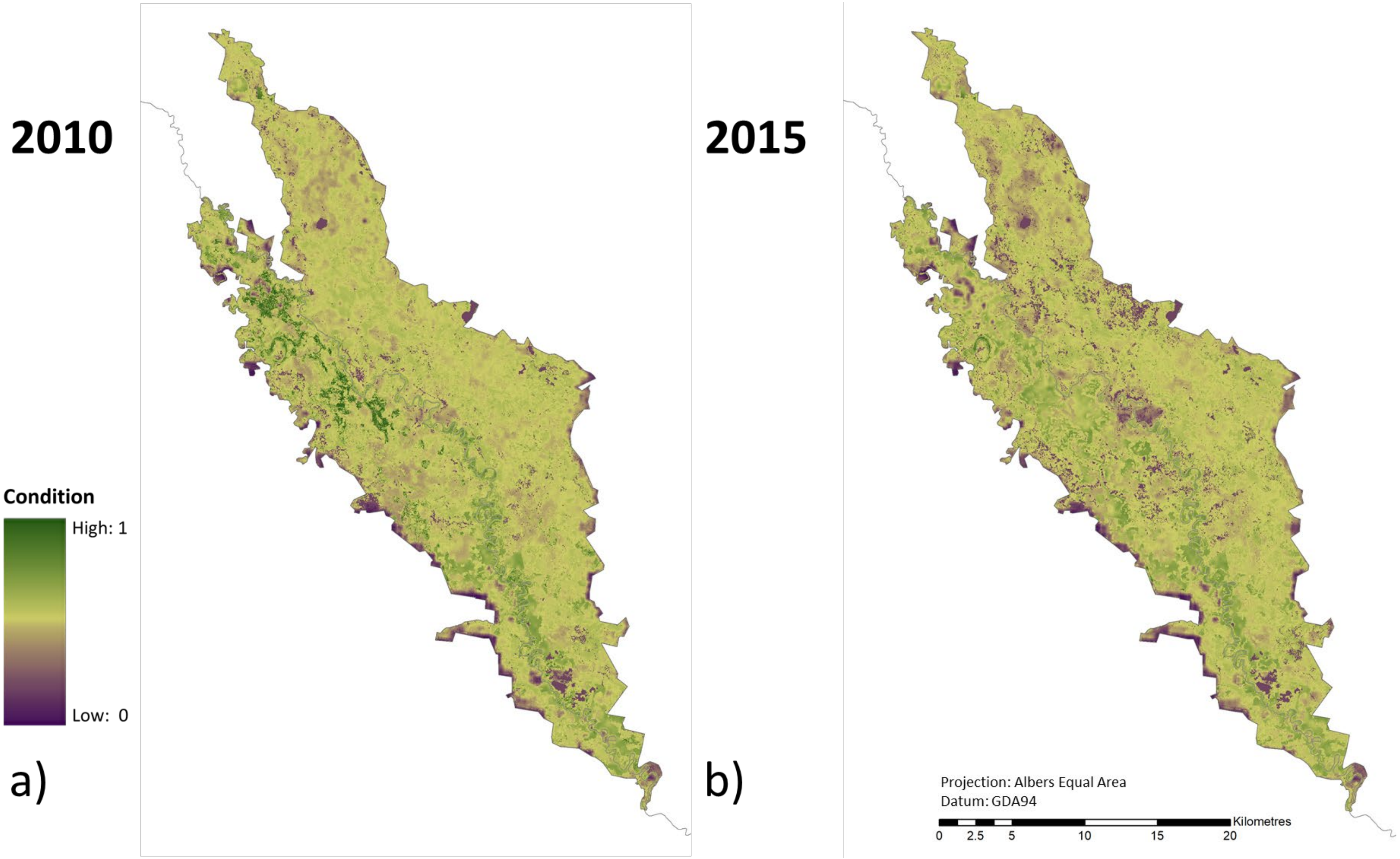
Ecosystem condition	Inland floodplain eucalypt forests and woodlands		Re-sprouter temperate and subtropical eucalypt woodlands		Fire-intolerant *Callitris* woodlands		Wetlands		Lowland streams		Cultivated		Unclassified		Total	
	Opening value 2010	Closing value 2015	Opening value 2010	Closing value 2015	Opening value 2010	Closing value 2015	Opening value 2010	Closing value 2015	Opening value 2010	Closing value 2015	Opening value 2010	Closing value 2015	Opening value 2010	Closing value 2015	Opening value 2010	Closing value 2015
Ecosystem condition index	0.498	0.479	0.612	0.609	0.194	0.195	0.471	0.471	0.583	0.583	0.303	0.309	0.529	0.562	0.498	0.481

Note:

1. For the 'lowland streams' ecosystem type, expert-derived condition scores were used, as the terrestrial HCAS habitat condition scores are not applicable for this aquatic ecosystem type.
2. For the 'cultivated' and 'unclassified' ecosystem types, HCAS ecosystem condition scores are reported, as no expert-derived condition scores were available.

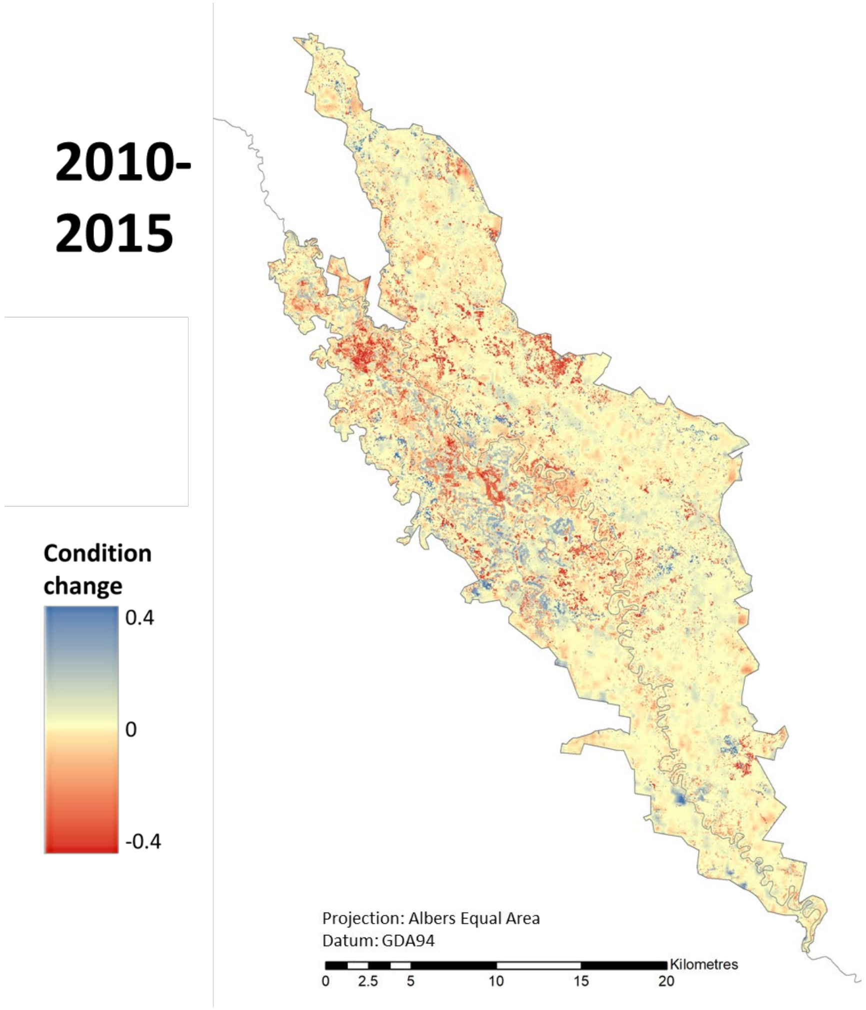
Source: Harwood et al. (2021a, 2021b)

Figure 12 Ecosystem condition index for a) 2010 and b) 2015



Note: The maps represent a combination of continuous data for most states, and categorical data for the three states in which HCAS was not used.
Source: Harwood et al. (2021a, 2021b)

Figure 13 The change in ecosystem condition index between 2010 and 2015



Note: Blue colours indicate an improvement in condition and red values a decline. Actual condition change exceeded the +/- 0.4 range in a small number of cells.
Source: Harwood et al. (2021a, 2021b)

Table 20 Ecosystem condition index account, by ecosystem type, Gunbower, 2010 to 2015

Ecosystem condition	Inland floodplain eucalypt forests and woodlands		Re-sprouter temperate and subtropical eucalypt woodlands		Fire-intolerant *Callitris* woodlands		Wetlands		Lowland streams		Cultivated		Unclassified	
	Opening value 2010	Closing value 2015	Opening value 2010	Closing value 2015	Opening value 2010	Closing value 2015	Opening value 2010	Closing value 2015	Opening value 2010	Closing value 2015	Opening value 2010	Closing value 2015	Opening value 2010	Closing value 2015
Ecosystem condition index	0.506	0.485	0.593	0.592	0.470	0.481	0.452	0.447	0.580	0.580	0.291	0.295	0.334	0.446

Notes:

1. For the 'lowland streams' ecosystem type, expert-derived condition scores were used, as the terrestrial HCAS habitat condition scores are not applicable for this aquatic ecosystem type.
2. For the 'cultivated' and 'unclassified' ecosystem types, HCAS ecosystem condition scores are reported, as no expert-derived condition scores were available.

Source: Harwood et al. (2021a, 2021b)

Table 21 Ecosystem condition index account, by ecosystem type, Koondrook-Perricoota, 2010 to 2015

Ecosystem condition	Inland floodplain eucalypt forests and woodlands		Re-sprouter temperate and subtropical eucalypt woodlands		Fire-intolerant *Callitris* woodlands		Wetlands		Lowland streams		Cultivated		Unclassified	
	Opening value 2010	Closing value 2015	Opening value 2010	Closing value 2015	Opening value 2010	Closing value 2015	Opening value 2010	Closing value 2015	Opening value 2010	Closing value 2015	Opening value 2010	Closing value 2015	Opening value 2010	Closing value 2015
Ecosystem condition index	0.493	0.475	0.630	0.625	0.177	0.170	0.479	0.474	0.578	0.557	0.438	0.477	0.652	0.628

Notes:

1. For the 'lowland streams' ecosystem type, expert-derived condition scores were used, as the terrestrial HCAS habitat condition scores are not applicable for this aquatic ecosystem type.
2. For the 'cultivated' and 'unclassified' ecosystem types, HCAS ecosystem condition scores are reported, as no expert-derived condition scores were available.

Source: Harwood et al. (2021a, 2021b)

Table 22 Ecosystem condition index, reported by areas (ha) with discretised ranges, 2010 to 2015

Extent (ha)	0.00 to 0.10	0.10 to 0.20	0.20 to 0.30	0.30 to 0.40	0.40 to 0.50	0.50 to 0.60	0.60 to 0.70	0.70 to 0.80	0.80 to 0.90	0.90 to 1.00	Total
Opening extent	213	2,411	731	2,463	21,896	22,512	4,110	448	767	475	56,025
Additions to extent											
Managed expansion	–	–	–	–	–	–	–	–	–	–	–
Unmanaged expansion	–	–	–	–	–	–	–	–	–	–	–
Unclassified expansion	59	2,732	521	1,816	6,392	6,455	2,169	253	11	1	20,409
Total additions	59	2,732	521	1,816	6,392	6,455	2,169	253	11	1	20,409
Reductions in extent											
Managed reduction	–	–	–	–	–	–	–	–	–	–	–
Unmanaged reduction	–	–	–	–	–	–	–	–	–	–	–
Unclassified reduction	76	1,332	370	1,393	7,629	6,638	1,463	314	718	475	20,409
Total reductions	76	1,332	370	1,393	7,629	6,638	1,463	314	718	475	20,409
Net change in extent	−17	1,401	151	423	−1,238	−183	706	−61	−708	−475	–
Closing extent	196	3,812	882	2,885	20,658	22,329	4,817	387	59	1	56,025

Note: '–' = 0
Source: Harwood et al. (2021b)

Table 23 Ecosystem condition index, by ecosystem state, 2010 to 2015

Ecosystem type	Ecosystem state	Ecosystem condition index*	
		2010	2015
Inland floodplain eucalypt forests and woodlands	Reference	0.860	0.687
	Modified: Reduced tree canopy over invaded understorey	0.457	0.455
	Modified: Invaded mature floodplain eucalypt forests and woodlands	0.596	0.584
	Modified: Invaded mature floodplain eucalypt forests and woodlands *or* Reduced tree canopy over invaded understorey**	0.503	0.500
	Modified: Halophytic state	0.160	0.160
Re-sprouter temperate and subtropical eucalypt woodlands	Reference	Na	Na
	Modified: Grey box woodlands with exotic understorey	0.612	0.609
Fire-intolerant *Callitris* woodlands	Reference	Na	Na
	Modified: Low-rise sandhill pine woodlands	0.470	0.481
	Modified: High-rise sandhill pine woodlands	0.170	0.170
Wetlands	Reference	Na	Na
	Modified: High-condition wetlands	0.794	0.779
	Modified: Moderate-condition wetlands *or* Low-condition wetlands†	0.469	0.469
Lowland streams	Reference	Na	Na
	Modified: Managed flows	0.583	0.583
Cultivated areas	Cultivated areas	0.303	0.309
Unclassified	Unclassified	0.529	0.562

Note: Na = not applicable; '–' = 0.
* Combined HCAS and expert-elicited condition scores
**In this area, the extent of the 'reduced tree canopy over invaded understorey' modified state could not be distinguished from the extent of the 'invaded mature floodplain eucalypt forests and woodlands' modified state.
†The extent of the 'moderate-condition wetlands' modified state could not be distinguished from the extent of the 'low-condition wetlands' modified state.
Source: Harwood et al. (2021a, 2021b)

Table 24 Ecosystem condition index by ecosystem type, with further detail on opening and closing percentage of area in each ecosystem state, 2010 to 2015

Ecosystem type	**Inland floodplain eucalypt forests and woodlands**					**Re-sprouter temperate and subtropical eucalypt woodlands**		**Fire-intolerant *Callitris* woodlands**			**Wetlands**			**Lowland streams**		**Cultivated area**	**Un-classified**
	R	**M**	**M**	**M**	**M**	**R**	**M**	**R**	**M**	**M**	**R**	**M**	**M**	**R**	**M**	**M**	**M**
Ecosystem state	**Reference**	**Reduced tree canopy**	**Invaded mature**	**Reduced tree canopy cover *or* Invaded mature***	**Halophytic state**	**Reference**	**Grey box woodlands**	**Reference**	**Low-rise sandhill pine**	**High-rise sandhill pine**	**Reference**	**High-condition**	**Moderate *or* low condition†**	**Reference**	**Managed flows**	**Not applicable**	**Not applicable**
Opening area in each ecosystem state, as a percentage of the area in its ecosystem type (%)	3	55	10	29	3	–	100	–	8	92	–	1	99	–	100	100	100
Opening ecosystem condition index for ecosystem type			0.498			0.612			0.194			0.471			0.583	0.303	0.529
Closing area in each ecosystem state, as a percentage of the area in its ecosystem type (%)	–	51	15	28	6	–	100	–	8	92	–	1	99	–	100	100	100
Closing ecosystem condition index for entire ecosystem type			0.479			0.609			0.195			0.471			0.583	0.309	0.562

Note: '–' = 0; 'R' = 'Reference'; 'M' = 'Modified'.

*In this area, the extent of the 'reduced tree canopy over invaded understorey' modified state could not be distinguished from the extent of the 'invaded mature floodplain eucalypt forests and woodlands' modified state.

†The extent of the 'moderate-condition wetlands' modified state could not be distinguished from the extent of the 'low-condition wetlands' modified state.

Source: Harwood et al. (2021a, 2021b)

6 Ecosystem services accounting

6.1 Introduction

Ecosystem services accounting involves recording the flows of services provided by an ecosystem, and the use of those services by economic units, i.e. households, governments and businesses. The measurement of ecosystem services can be undertaken in physical and monetary terms and be used to reveal how the flows of ecosystem services relate to the health of the ecosystem and how human activity may be influencing the level of services. Further, ecosystem services can be measured over time to understand trends in the relationship between different economic units and ecosystems and the relative contribution of ecosystems to different social and economic benefits and broader well-being. Priority areas for management can be identified by comparing ecosystem services across spatial areas.

Importantly, flows of ecosystem services are connected to the extent and condition of ecosystem assets and thus the methods used to classify and record both extent and condition need to underpin the measurement of ecosystem services. Often scientific endeavours focus on only one aspect of the ecosystems, say extent, condition or services. Consequently, combining and interpreting the results can be quite challenging and often not possible. Following environmental accounting principles and guidelines ensures information across all ecosystem domains (extent, condition, services and asset values) is coherent and can be unpacked to examine potential effects of changes in each domain.

The ecosystem services estimated within the Gunbower Koondrook-Perricoota (GKP) ecosystems (the ecosystem accounting area - EAA) fall into three broad categories: provisioning services, regulating and maintenance services and cultural services. The services to be estimated were selected and agreed on by the LEAP Team during the inception workshop. Following the SEEA EA ecosystem services reference list, provisioning services measured include the supply of native timber, firewood, honey and water supply. Regulating and maintenance services measured are global climate regulation (via carbon sequestration and stock) and pollination. Spiritual, artistic and symbolic services (via cultural heritage connection) and recreation-related services are the cultural services considered.

Where data is available, and benefits can be quantified within the SEEA EA accounting framework, each ecosystem service will contribute to a benefit. In some cases, the benefits are goods and services already recorded as monetary transactions, for example, sales of timber and honey. In other cases, the benefits concerning improvements in, for example, health, are not recorded as monetary transactions. In all cases ecosystem services accounting focuses on recording the flows of ecosystem services but, as relevant, data on the related benefits is also presented.

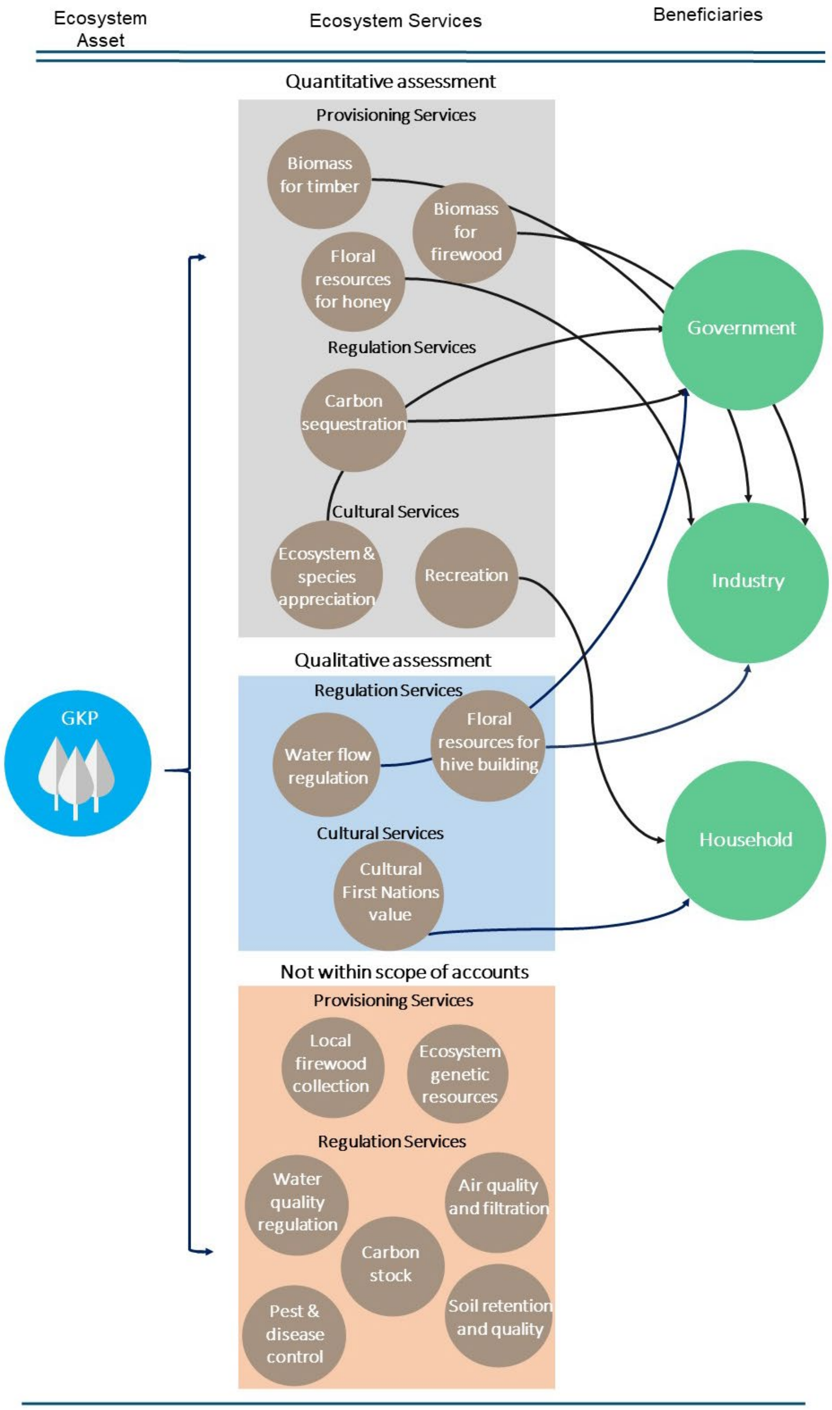
Use of ecosystem services may be competing (for example, use of timber provisioning services will compete with global climate regulation services) or may be complementary (for example, floral resources for honey and recreation services). Ecosystem accounting allows these relationships to be recorded consistently. The use of ecosystem services may be a potential pressure on the ecosystems within GKP. Possible pressures include logging for timber and firewood supply, pollution from recreational vehicles (for example, fishing boats) and people inadvertently damaging ecosystems while recreating. Throughout this section there is information on intensity of use, which may be used to assess the potential environmental and economic sustainability of different uses.

Ecosystems may also have negative effects on people (for example, pests may reduce the recreational experience of campers), these are generally reflected in reduced ecosystem service flows.

Where services are quantified, they are measured in terms of physical and monetary flows (for example, in kgs and dollars, respectively). Estimates in monetary terms are based on either use or non-use of exchange values as defined in the SEEA EA. Complementary monetary measures using welfare values (i.e. including consumer surplus) have been included for carbon sequestration. Physical and monetary flows are not calculated for all services. In particular, a qualitative description of the cultural significance of the Gunbower Island ecosystems to members of the Barapa Barapa and Yorta Yorta language groups is included in-lieu of accounting entries (p.131). Also, calculation of the monetary supply and use for carbon sequestration are included, but not carbon stocks. This is explained in detail in the carbon sequestration and stocks section of this paper. Figure 14 summarises which ecosystem services are and are not included in the analysis and how they connect to different beneficiaries.

All supply and use tables in this report include a statement on the confidence in the data (for physical supply and use) and the estimate (for monetary supply and use), based on the opinions of the authors.

Figure 14 Beneficiaries diagram



Note: Ecosystem and species appreciation services are a non-use value. All other services assessed quantitatively involve use values. See Table 25 for more details.

The results of the ecosystem services section are summarised in each individual section of section 6. For each service there is a unit of measure, a quantity, a user, a time period and an ecosystem type that the quantity relates to. The relationship between beneficiaries and the environment can be characterised as comprising of both use and non-use values. Use values arise where the benefit to people is revealed through their direct, personal interaction (for example, harvesting food, hiking in forests, benefitting from cleaner air), or through indirect use (for example, regulation of water flows providing flood mitigation) of the environment. Use values are the focus of measurement within the SEEA EA. Non-use values are those values that people assign to ecosystems (including associated biodiversity), irrespective of whether they use (directly or indirectly), or intend to use, the ecosystems. The existence of biodiversity and the desire for its ongoing preservation is also connected to non-use values that people hold with respect to the environment (UNCEEA 2021).

Use and non-use values can be measured using exchange and welfare values. Exchange values value ecosystem services and assets at the prices at which they are exchanged, or would be exchanged if markets were present. Exchange values satisfy the requirements of the SEEA-EEA accounting framework because the approach supports comparison of ecosystem accounting monetary values with those recorded in conventional economic and financial accounts. However, EEA recognises that the exchange valuation approach applied in ecosystem accounting does not provide a comprehensive measure of the value of nature. In particular, the monetary values captured in the SEEA framework likely reflect a sub-set of all ecosystem services and exclude measures of consumer surplus that may be of analytical interest in many contexts.

To gain a more holistic understanding of consumer surplus, welfare values are presented alongside exchange values in this report. Welfare values are economic values that reflect the economic wellbeing consumers receive from ecosystem assets. The welfare derived from a good or service is equal to the total willingness-to-pay (WTP) for it, which includes the payment made (in or outside of market transactions) and the consumer surplus. Welfare values sit outside the SEEA-EEA compliant environmental economic accounts but are presented to further inform policy decisions. Where welfare values are presented, they are clearly identified and should be considered independent to the exchange values. Welfare values and exchange values are not additive and care should be taken to avoid double counting. Table 25 summarises how the monetary values for each ecosystem service in section 6 is presented. Note that Carbon sequestration services are presented in terms of both exchange and welfare values and that ecosystem and species appreciation is a non-use value. The non-use value of ecosystem and species appreciation concerns the wellbeing that people derive from the existence and preservation of the environment for current and future generations, irrespective of any direct or indirect use.

Care is required when relying on accounting outputs for decision making. Both the information and its accuracy vary across ecosystem services in terms of spatial and temporal coverage. Several techniques have been used to estimate the quantity of ecosystem services. Each have their own limitations and, in most instances, additional data collection would improve the results. More information on the results and caveats are provided throughout section 6.

Table 25 Ecosystem service valuation method summary

Ecosystem service	Exchange value		Welfare value		Use or non-use value
	Presented	Table reference	Presented	Table reference	
Biomass for timber	Yes	Table 28	Yes	As Exchange	Use value
Biomass for firewood	Yes	Table 31	-	-	Use value
Floral resources for honey	Yes	Table 33	Yes	As Exchange	Use value
Carbon Sequestration and Stock	Yes	Table 37 Table 38	Yes	Table 39	Use value
Floral resources for hive building	-	-	-	-	Use value
Ecosystem and species appreciation	Yes	Table 42	-	-	Non-use value
Water flow regulation	-	Table 44	-	-	Use value
Ecosystem services and First Nations Australians	-	-	-	-	Use and non-use value
Recreation	Yes	Table 47	Yes	In Text	Use value

Note: '–' means the valuation method was not included in this analysis

6.2 Wood provisioning services - biomass for timber

The GKP ecosystems provide biomass for commercial timber as a wood provisioning service. This service is quantified as the volume and quality of timber harvested from the Gunbower, Koondrook and Perricoota forests. The direct users of this ecosystem service are the NSW and Victorian state forestry departments, which benefit from any improvement in the condition of the forest that increases quality or quantity of their sawlog yields. Figure 15 shows the relationship between the ecosystem service and these users.

The main flow of interest in this context is the relationship between the GKP ecosystem and harvesters. The GKP ecosystem provides wood biomass for timber. Access rights to use this biomass are allocated by the government (in the form of quotas and licenses) which are reflected in the ecosystem services step as 'coupe harvesting' (Figure 15). In the GKP, ecosystem harvesting is completed by the FCNSW and VF. The quantity and quality of timber yield is a function of GKP ecosystem type and forest condition. The ecosystem type providing the service is inland eucalypt forests and woodlands. The benefits received by the local economy are the resource rent attributable to the ecosystem. Resource rents are described in Box 5 below and incorporate the portion of benefits to local economy that are reliant on the ecosystem as an input, separate from other inputs like machinery and labour.

There are other relationships that are not captured explicitly in Figure 15 but are important to consider in forest management. These include that not all biomass is allocated by government for harvest by FCNSW and VF. Trees that are not allocated for harvest remain in the forest ecosystem and can benefit other species or contribute to user experience (for example, camping). The link between the ecosystem (quantity and quality), the biomass (quantity and quality), and the transactions are key components of the narrative. A complete information set will capture each activity or transaction, estimate the value of those transactions, and link them to an ecosystem asset to understand how the attributes and condition of the ecosystem affects the transaction. Government can contribute to the set of information outlined in Figure 15 to support the ongoing management of the GKP ecosystem. An overview of timber harvesting areas in Gunbower, Koondrook and Perricoota foreststs is provided in Figure 16 and Figure 17.

Figure 15 Biomass for timber services

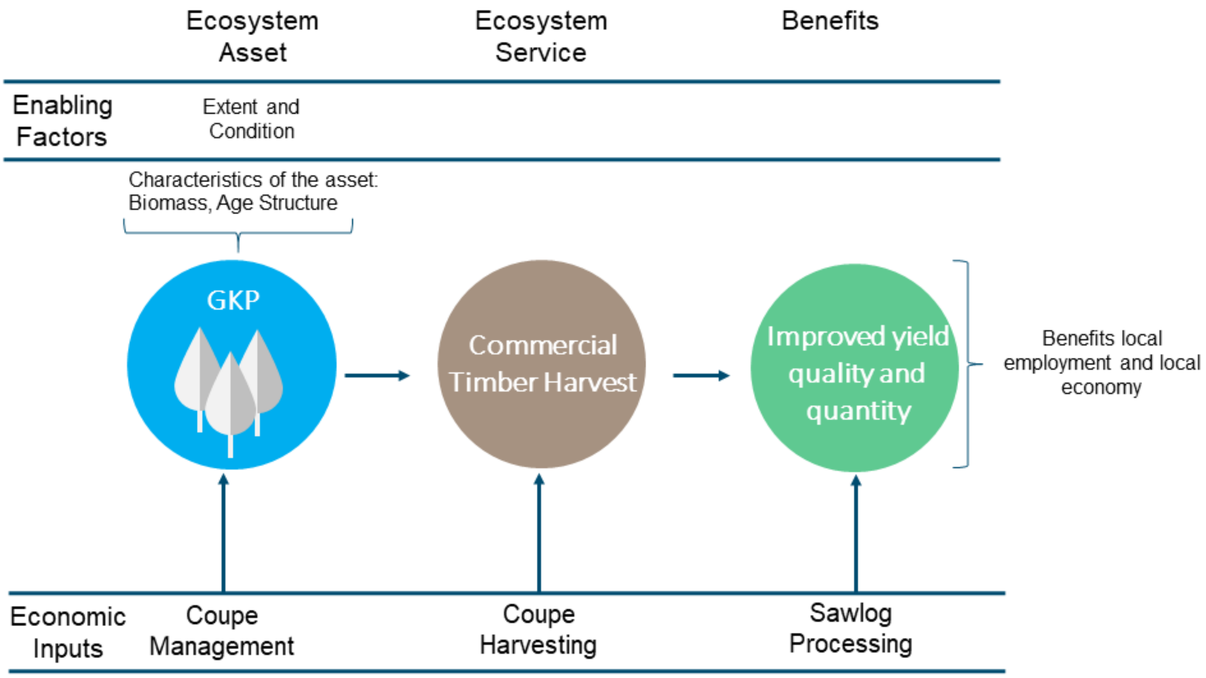
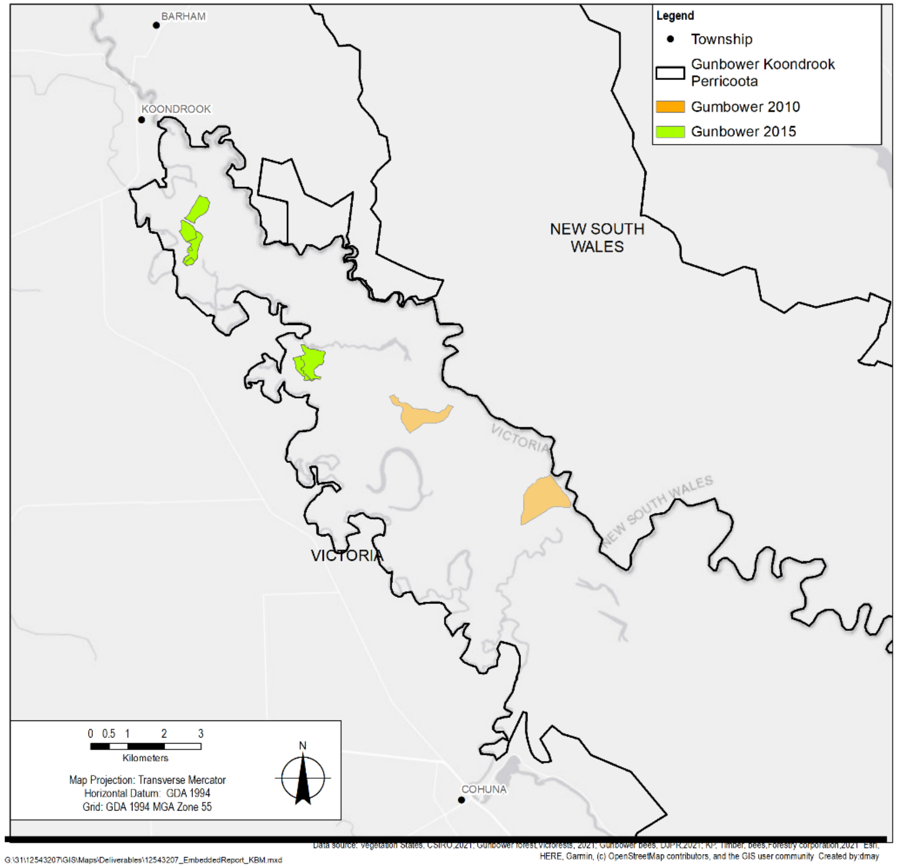
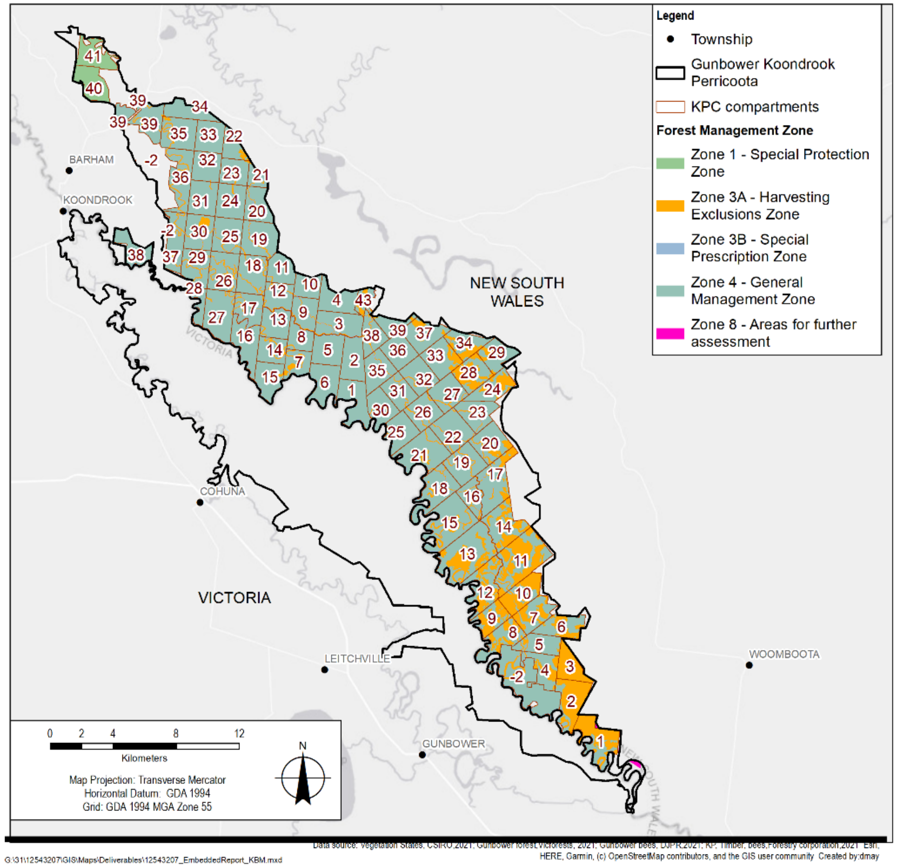


Figure 16 Timber and firewood harvesting areas Gunbower forest



Source: Ecosystem types (Richards et al. 2021a, 2021b), Gunbower Forestry compartments Open data DATA VIC, OpenStreetMap

Figure 17 Timber and firewood harvesting compartments in Koondrook-Perricoota



Source: Ecosystem types (Richards et al. 2021a, 2021b), Dedicated timber reserves, Forestry management zones FCNSW, OpenStreetMap

6.2.1 Method

Physical and monetary ecosystem service accounts for 2010 and 2015 were produced in this analysis. A particular focus of the ecosystem service accounts was to integrate the account ready data on extent and condition outlined in chapters 1-5. A summary of the method for the physical supply and use is provided in box 4 and a summary of the method for the monetary supply and use is provided in box 5. Detailed methods for both ecosystem service accounts are outlined in (Cheesman et al. 2021). All datasets relied on for the analysis of ecosystem services are referenced at the bottom of the account tables.

Box 4 Approach to producing physical ecosystem service accounts

The physical ecosystem accounts for biomass for timber calculate the supply of each of the ecosystem services. The valuation of physical ecosystem service accounts for biomass for timber is as follows:

- Timber harvesting spatial data for Gunbower forest and Koondrook-Perricoota identify the timing and areas harvested across all years providing data for target years and annual harvesting across the site. Spatial data also identifies management exclusion zones including waterways, wetlands and high value vegetation.
- The provision of native timber (tonnes and volumes) to the timber industry from the GKP was then quantified.
- This structured approach incorporated significant amounts of on-ground ecological survey data from North Central Catchment Management Authority, MDBA and FCNSW and yield data from FCNSW and VF to ensure that the physical ecosystem service accounts closely reflect reality.

Note: The approach is explained in full in the accompanying technical report
Source: (Cheesman et al. 2021)

Box 5 Approach to producing monetary ecosystem service accounts

The monetary ecosystem accounts for biomass for timber calculate the exchange value of the ecosystem services determined under the physical ecosystem accounts. The ecosystem service of biomass for timber can be valued by applying a residual rent dollar value to each tonne of timber yield in 2010 and 2015 respectively. This relationship is represented by:

$$\$ES_{ti,y,i,t,e} = Ti_{y,i,t,z} * RR_{y,i,t}$$

Where:

$\$ES_{ti,y,i,t,e}$ is the value of the timber harvest (ti), in year (y), at geographic location (i), ecosystem type (t), measured as an exchange value (e)

$Ti_{y,i,t,z}$ is the timber yield (tonnes) in year (y), from geographic location (i), ecosystem type (t), for quality (z)

$RR_{y,i,t}$ is the per unit (tonne) residual rent from harvested timber in year (y) from location (i), ecosystem type (t).

A general description of how monetary ecosystem accounts for biomass for timber were produced is outlined below:

- The biomass for timber supplied to industry was interrogated. This is summarised in the physical ecosystem accounts described in Box 4.

- The residual rents approach is used to value the supply of biomass for timber. Residual rent of timber harvesting is estimated as the royalty value (stumpage value) of timber for sawlogs in the GKP ecosystem less depreciation costs. This represents the residual economic value that the harvester of the sawlog gains after all costs of extraction (transport of timber to mill door) or use (mill processing) and normal returns from production have been considered. Importantly, resource rent is not the revenue from the sales, nor the gross operating surplus. These types of values will overstate the residual rent attributable to the biomass for timber. The exchange based residual rents approach is covered in detail in the technical report (Cheesman et al. 2021).
- The residual rents per unit of biomass for timber supply are multiplied by the physical supply units to determine the exchange value.

Note: The approach is explained in full in the accompanying technical report
Source: Cheesman et al. (2021)

Gunbower timber harvest was only identified as sawlogs and not graded. Tonnage was based on converting volumes to tonnes using a multiplication factor of 1.3 (volume x 1.3 = tonnes). For Koondrook-Perricoota sawlog grades were provided indicating a variable harvest of sawlog quality in 2010 and 2015 (Table 26). Overall harvest was significantly greater in 2010 than 2015.

Table 26 Summary of sawlog grades harvested from Koondrook-Perricoota in 2010 and 2015

Timber type	Sum of 2010 tonnes	Sum of 2015 tonnes
Large Sawlog	0	170.48
Miscellaneous Grade 1		8.62
Salvage Grade 1	33579.25	8416.15
Salvage Grade 2	1212.8	
Sawlog	12234.84	
Small Sawlog	0	0
Grand Total	47026.89	8595.25

Note: from locations provided in Figure 16 and Figure 17.
Source: FCNSW

Areas harvested in Gunbower and Koondrook-Perricoota in 2010 and 2015 are from spatially separate coupes with no additional harvest between 2011 and 2014 this reduces additional managed losses from logging the same compartments in consecutive years.

6.2.2 Areas for improvement

Additional research should focus on improving the central collection and open access to ecosystem supply data. This analysis collated information on the biomass for timber provided by the GKP ecosystem from several different sources with varying levels of difficulty. Data resourcing for use in ecosystem accounting should be organised to assist future calculations. Data sources were variable in relation to detailed site information such as harvest plans, predicted yields and coupe logging volumes and tonnage. Biomass for timber supply data should be supplemented with detailed records of use data: the costs of harvest and transport and the stumpage value compared to the mill door value of sawlog timber yielded. This approach will streamline the calculation of residual rents of ecosystem supply to ensure account accuracy. This will provide managers with an improved understanding of what the ecosystem is providing to different stakeholders and substantially improve their ability to make management decisions.

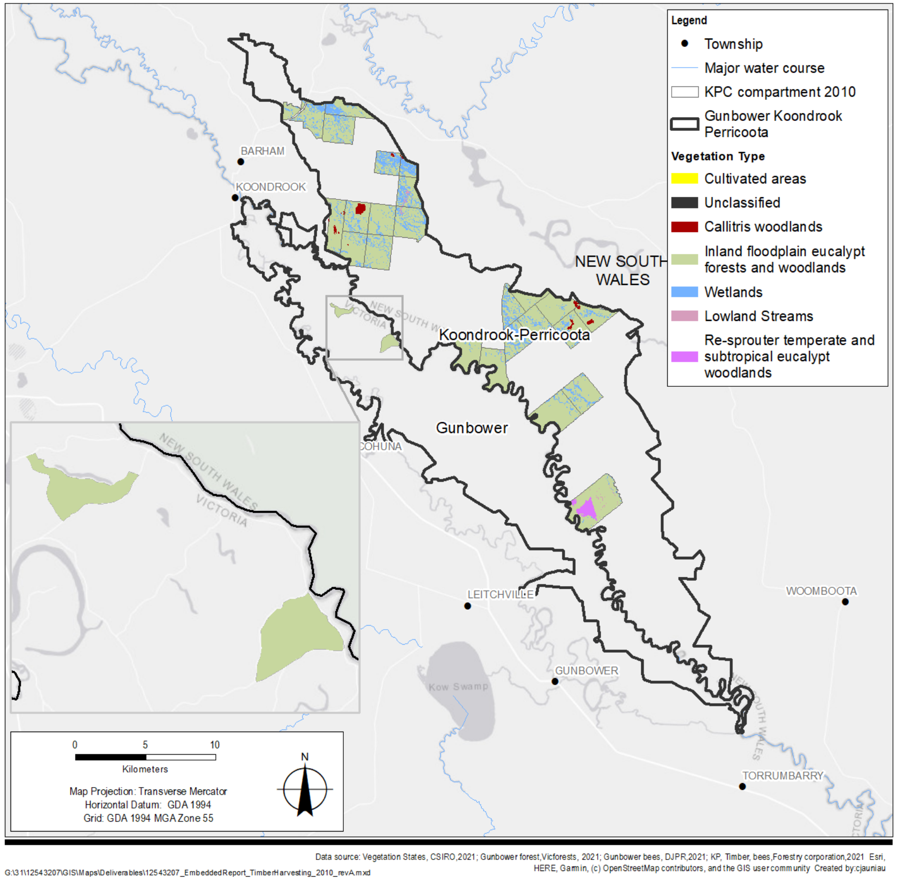
6.2.3 Accounting outputs

A biomass for timber physical supply and use table (Table 27) and monetary supply and use table (Table 28) were developed for the ecosystem accounting area. Supply and use tables show the relationship between biomass for timber supplied in 2010 and 2015, the GKP ecosystem, with the forestry industry as the user. This approach aligns with the SEEA framework (UNCEEA, 2021).

The physical supply and use table (Table 27) illustrates tonnes of biomass for timber harvested from Gunbower forest and Koondrook-Perricoota forest in 2010 and 2015. A minimum of 962 tonnes and 432 tonnes of biomass for timber were harvested from Gunbower forest in 2010 and 2015 respectively. A biomass of 4,809 tonnes for timber were harvested from Koondrook-Perricoota forest in 2010 and 8,595 tonnes in 2015. A biomass of 47,988 total tonnes of for timber were harvested across the GKP ecosystem in 2010, this dropped to 9,027 tonnes of total yield in 2015. Biomass for timber was only harvested from the inland floodplain eucalypt forests and woodlands and use is allocated to the forestry industry.

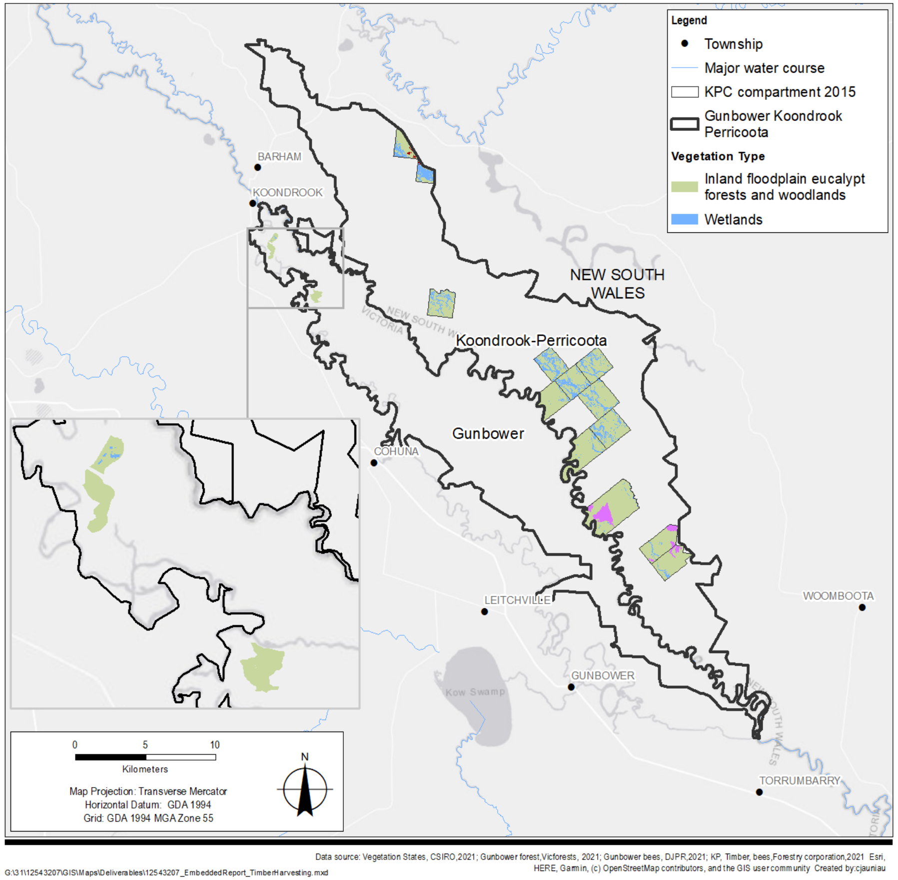
The monetary supply and use table (Table 28) outlines the residual rents associated with the biomass for timber harvested in 2010 and 2015. The 432 tonnes harvested from Gunbower forest and 8,595 tonnes from Koondrook-Perricoota in 2015 have a residual rent of $30,000 and $393,000 respectively. This equates to a total monetary supply of around $423,000. This is the total value of the timber, less the costs of harvest and depreciation. Timber harvested in 2010 had a total monetary supply of around $868,000, $66,000 of that total was supplied by the Gunbower forests and $802,000 by the Koondrook-Perricoota forest.

Figure 18 GKP timber harvesting compartments accessed in 2010



Source: Ecosystem types (Richards et al 2021a,b), Gunbower Forestry compartments Open data DATA VIC, OpenStreetMap

Figure 19 GKP timber harvesting compartments accessed in 2015



Source: Ecosystem types (Richards et al 2021a,b), Dedicated timber reserves, Forestry management zones FCNSW, OpenStreetMap

Table 27 Biomass for timber physical supply and use table, GKP, 2010 and 2015

		Economic units			Ecosystem type											
					Gunbower						Koondrook-Perricoota					
Supply /Use	Units	Household	Government	Industries	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams
2010																
Supply	tonnes				-	962	-	-	-	-	-	47,026	-		-	-
Use	tonnes			47,988												
2015																
Supply	tonnes				-	432	-	-	-		-	8,595	-		-	-
Use	tonnes			9,027												

Note: Supply and use of biomass for timber is derived from 2010 and 2015 yields. Yields data was measured in tonnes and m3 across specific coupes (Ha). Confidence in data is high. Sawlog yield data from FCNSW was defined by sawlog quantity and quality across different harvesting areas in Koondrook-Perricoota forests. Yield data from Victorian Department of Jobs, Precincts and Regions was averaged and contains some uncertainty. Estimates can be improved with finer scale collection of timber yield data within the harvested coupes that identifies go and no go areas, especially within NSW forestry coupes. '–' = 0

Source: Data from (Victorian Department of Jobs, Precincts and Regions(2021) and FCNSW (2021)

Table 28 Biomass for timber monetary supply and use summary table, GKP, 2010 and 2015

		Economic units			Ecosystem type											
					Gunbower						Koondrook-Perricoota					
Supply/Use	**Units**	**Household**	**Government**	**Industries**	**Fire-intolerant *Callitris* woodlands**	**Inland floodplain eucalypt forests and woodlands**	**Wetlands**	**Cultivated areas**	**Re-sprouter temperate and subtropical eucalypt woodlands**	**Lowland Streams**	**Fire-intolerant *Callitris* woodlands**	**Inland floodplain eucalypt forests and woodlands**	**Wetlands**	**Cultivated areas**	**Re-sprouter temperate and subtropical eucalypt woodlands**	**Lowland Streams**
2010																
Supply	$ AUD				-	66,000	-	-	-	-	-	802,000	-	-	-	-
Use	$ AUD			868,000												
2015																
Supply	$ AUD				-	30,000	-	-	-	-	-	393,000	-	-	-	-
Use	$ AUD			423,000												

Note: Residual rents of biomass for timber are derived from 2010 and 2015 royalty estimates and are presented in nominal terms. Residual rents are the total monetary output less the costs of timber harvest and depreciation. Confidence in estimates is high. Sawlog royalties have been adjusted based on evidence from Victorian Department of Jobs, Precincts and Regions and New South Wales Department of Primary Industries. Yield values from Gunbower forest include some uncertainty and are averages across the thinned region (Ha). Estimates can be improved with finer scale collection of timber yield and related variable and fixed cost data. '–' = 0
Source: Data from Victorian Department of Jobs, Precincts and Regions (2021) and NSW Department of Primary Industries (2017)

6.3 Wood provisioning service - biomass for firewood

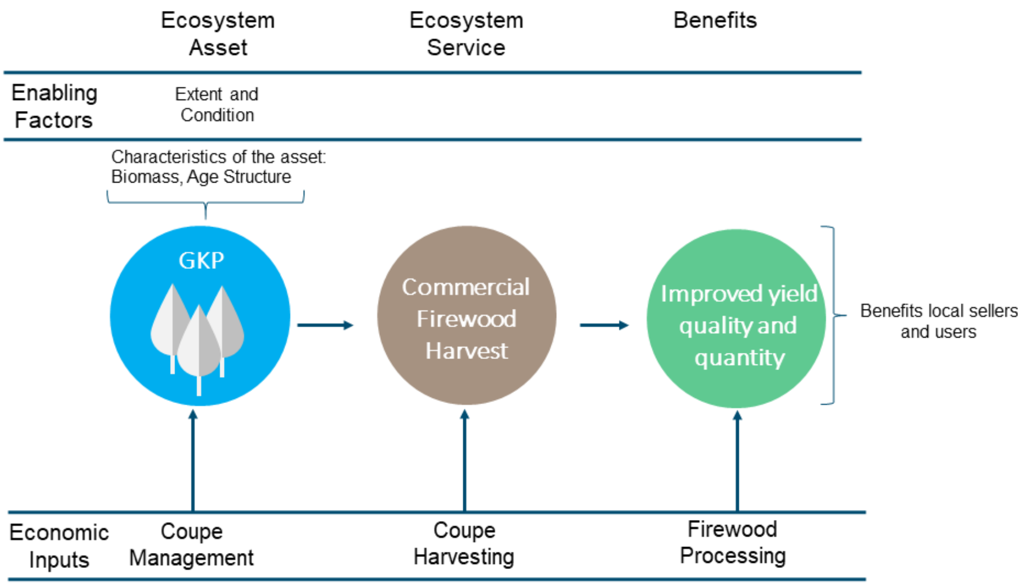
The GKP ecosystem provides biomass for commercial firewood as a wood provisioning service in the same way that it provides biomass for commercial timber. Provision of biomass for commercial firewood is quantified as the volume and quality of firewood harvested from the Gunbower, Koondrook and Perricoota forests in the target years. The direct user of this ecosystem service is the local timber industry, which benefits from any improvement in the condition of the forest that increases quality or quantity of their firewood yields. Figure 20 shows the relationship between the ecosystem service and users. Note that this analysis doesn't include domestic firewood collection.

The main flow of interest in this context is the relationship between the GKP ecosystem and users. The government allocates access rights to the use of the wood biomass (in the form of quotas and licenses) which are reflected in the ecosystem services step as 'coupe harvesting' (Figure 20). FCNSW and VF complete firewood harvesting in the GKP ecosystem in the same way they complete sawlog harvesting. The quantity and quality of firewood yield is a function of GKP ecosystem type and forest condition. The ecosystem type providing the service is inland eucalypt forests and woodlands.

There are other relationships that are not captured explicitly in Figure 20 but are important to consider in forest management. The biomass is allocated by government for harvest by FCNSW and VF. Trees that are not harvested remain within the forest ecosystem to benefit other species or contribute to user experience (for example, camping). The link between the ecosystem (quantity and quality), the biomass (quantity and quality), and the transactions are key components of the narrative.

A complete information set will capture each activity or transaction, estimate the value of those transactions, and link them to an ecosystem asset to understand how the attributes and condition of the ecosystem affects the transaction. Government can contribute to the set of information outlined in Figure 20 to support the ongoing management of the GKP ecosystem.

Figure 20 Biomass for firewood services



6.3.1 Method

Physical and monetary ecosystem service accounts were produced for biomass for firewood. As with the biomass for timber accounts, a particular focus of the ecosystem service accounts was to integrate the account ready extent and condition data outlined in the previous chapters. A summary of the method for the physical supply and use is provided in Box 6 and a summary of the method for the monetary supply and use is provided in Box 7. Detailed methods for both ecosystem service accounts are outlined in the technical report (Cheesman et al., 2021). All datasets relied on for the analysis of ecosystem services are referenced at the bottom of the account tables.

Box 6 Approach to producing physical ecosystem service accounts

The physical ecosystem accounts for biomass for firewood calculate the supply of each of the ecosystem services. The valuation of physical ecosystem service accounts for biomass for firewood is as follows:

- Timber harvesting spatial data for Gunbower forest and Koondrook-Perricoota identify the timing and areas harvested for firewood across all years providing data for target years and annual harvesting across the site. Timber harvested for firewood was defined separately from broader timber harvesting. Spatial data also identifies management exclusion zones including waterways, wetlands and high value vegetation.
- The vegetation characteristics (ecosystem type and state) contributing to the service are defined.
- The provision of native timber for firewood (tonnes and volumes) to the timber industry from the GKP was then quantified.
- This structured approach incorporated significant amounts of on-ground ecological survey data from CSIRO and yield data from VicForests/NSW Forest Corp to ensure that the physical ecosystem service accounts closely reflect reality.

Note: The approach is explained in full in the accompanying technical report
Source: Cheesman et al. (2021)

Box 7: Approach to producing monetary ecosystem service accounts

The monetary ecosystem accounts for biomass for firewood calculate the exchange value of the ecosystem services determined under the physical ecosystem accounts. The ecosystem provision service of biomass for firewood supply can be valued by applying a residual rent dollar value to each tonne of firewood yield in 2010 and 2015 respectively. This relationship is represented by:

$$\$ES_{f,y,i,t,e} = F_{y,i,t,z} * RR_{y,i,t}$$

Where:

$\$ES_{f,y,i,t,e}$ is the value of the firewood harvest (f), in year (y), at geographic location (i), ecosystem type (t), measured as an exchange value (e)

$F_{y,i,t,z}$ is the firewood yield (tonnes) in year (y) from geographic location (i), ecosystem type (t) for quality (z)

$RR_{y,i,t}$ is the per unit (tonnes) residual rent from firewood in year (y) from location (i), ecosystem type (t).

A general description of how monetary ecosystem accounts for biomass for firewood were produced is outlined below:

- The biomass for firewood supplied to industry was interrogated. This is summarised in the physical ecosystem accounts described in Box 6.
- The residual rents approach is used to value the supply of biomass for firewood. The residual rent of firewood harvest is the royalty value (stumpage value) of timber for firewood in the GKP ecosystem less depreciation costs. This represents the residual economic value that the harvester of the firewood gains after all costs of extraction (transport to mill door) or use (mill processing) and normal returns from production have been considered. Importantly, resource rent is not the revenue from the sales exchange, nor the gross operating surplus. These values will overstate the residual rent attributable to the biomass for firewood and are not directly comparable to the methods and valuations for GKP as a result. The exchange based residual rents approach is covered in detail in the technical report (Cheesman et al., 2021).
- The residual rents per unit of biomass for firewood supply is multiplied by the physical supply units to determine the exchange value.

Note: The approach is explained in full in the accompanying technical report
Source: Cheesman et al. (2021)

Areas harvested in Gunbower in 2010 and 2015 are from spatially separate coupes with no harvest occurring from 2011 to 2014. Area harvested in Koondrook-Perricoota include compartments where firewood harvesting has occurred during the intervening years (Table 29). Table 29 outlines the coupes harvested for firewood within Koondrook-Perricoota in 2010 and 2015 that were also harvested for firewood from 2011 to 2014. This is a subset of the coupes harvested for firewood in Koondrook-Perricoota in 2010 and 2015 and the total tonnes of physical supply only account for a portion of the supply presented in Table 30. It is anticipated firewood harvesting has been progressively implemented in these coupes as part of an overall harvest plan. Harvest plan details for coupes and time periods were not available to further assess these localities. This information would assist the assessment of overall anticipated yield and provide a way to assess the capacity of the system.

Table 29 Summary of firewood harvest from Koondrook-Perricoota coupes assessed in 2010 and 2015

Timber compartment	Unit	2010	2011	2012	2013	2014	2015
13	tonnes	818.74					5,834.24
19	tonnes	3597.3		25.28	3,168.26	8824.22	4,702.54
20	tonnes	822.04	93.96				
21	tonnes	211.38	93.92		14,809.78	3,450.19	2,727.9
22	tonnes	5059.6			4,182.5	925.08	7,169.61
23	tonnes			5,769.74			
24	tonnes			3,982.24			
25	tonnes	62.23					12,523.75
26	tonnes	1,131.56	119.1	119.01		221.18	9,974
29	tonnes	12,181.14		8,394.93	1,446.92		
30	tonnes	5,404.33	91.34				
Total	tonnes	29,288.32	398.32	18,291.2	23,607.46	13,420.67	42,932.04

Note: '–' = 0 Data indicates firewood was also harvested from these compartments between 2011 and 2014. (not all timber compartments accessed are shown)

6.3.2 Areas for improvement

The same areas for improvement for biomass for timber are relevant in relation to biomass for firewood supplied by the GKP ecosystem. In short, future research should continue to develop the data collection and distribution process. It should focus on providing open access to firewood harvest data and streamline collection of this data to ensure that large scale ecosystem accounting is feasible. A more precise understanding of harvest costs and depreciation costs for firewood should also be developed across different states and for different forestry departments. This would provide managers with a more complete picture of ecosystem supply and substantially improve their ability to make management decisions.

6.3.3 Accounting outputs

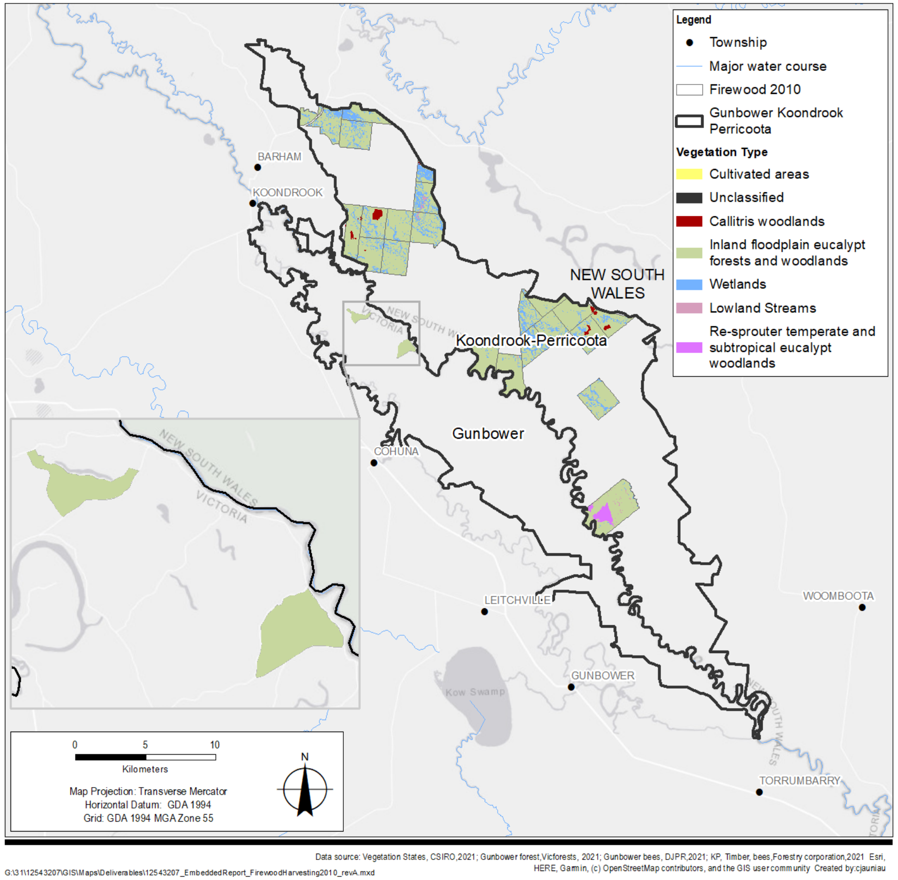
A biomass for firewood physical supply and use table (Table 30) and monetary supply and use table (Table 31) were developed for the accounting area in 2010 and 2015. Supply and use tables show the relationship between biomass for firewood supplied, the GKP ecosystem, and the government as the user.

In 2010, the physical supply and use table (Table 30) illustrates that a minimum of 4890 tonnes of biomass for firewood was harvested from Gunbower forest and 47,026 tonnes from Koondrook-Perricoota forest in 2010. The 2010 total firewood yield across GKP is 47,998 tonnes. All yield was harvested from the inland floodplain eucalypt forests and woodlands and is allocated to the local firewood industry.

The 2015, the physical supply and use table (Table 30) illustrates that a minimum of 2,162 tonnes of biomass for firewood was harvested from Gunbower forest and 55,775 tonnes from Koondrook-Perricoota forest. The 2015 total yield of 57,937 tonnes was exclusively harvested from the inland floodplain eucalypt forests and woodlands ecosystem type in both forests and is allocated to the firewood industry. The physical supply of firewood from Gunbower and Koondrook-Perricoota forest in 2015 is substantially lower than in 2010. It is expected that this variance is directly due to the harvest plans for the targeted coupes, as determined by VicForests and NSW Forest Corp respectively.

The monetary supply and use table (Table 31) presents the residual rents associated with the biomass for firewood harvested in 2010 and 2015. Total biomass for firewood harvested in 2010 has a residual rent of around $1,482,000. More firewood was harvested from Koondrook-Perricoota forest in 2015 than 2010, and the total residual rent of harvest from the GKP ecosystem in 2015 is around $1,159,000. These total exchange values for biomass for firewood includes the total sale value of the firewood less the costs of harvest, transport and depreciation.

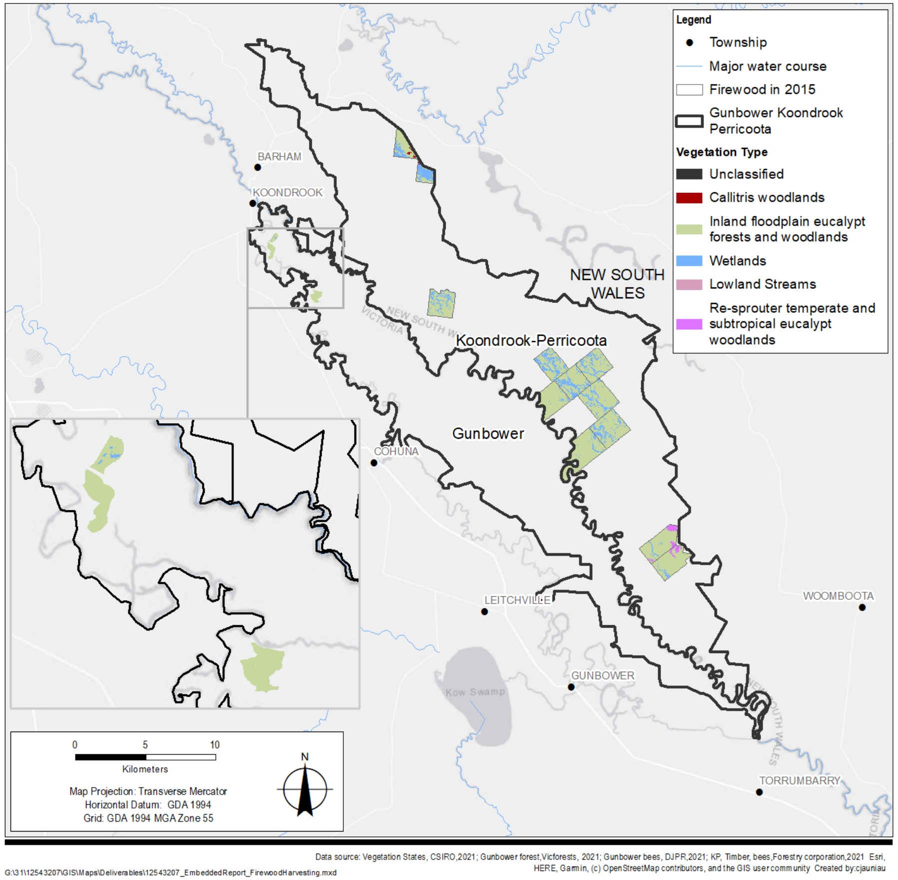
Figure 21 Firewood harvesting areas in 2010



Note

Source Ecosystem types (Richards et al 2021a,b), Gunbower Forestry compartments Open data DATA VIC, OpenStreetMap

Figure 22 Firewood harvesting areas in 2015



Note

Source Ecosystem types (Richards et al 2021a,b), Dedicated timber reserves, Forestry management zones FCNSW, OpenStreetMap

Table 30 Biomass for firewood physical supply and use table, GKP, 2010 and 2015

Supply/ Use	Units	Economic units			Ecosystem type											
					Gunbower						Koondrook-Perricoota					
		Household	Government	Industries	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams
2010																
Supply	tonnes				-	4,809	-	-	-	-	-	69,322	-	-	-	-
Use	tonnes			74,131												
2015																
Supply	tonnes				-	2,162	-	-	-	-	-	55,775	-	-	-	-
Use	tonnes			57,937												

Note: Supply and use of biomass for firewood is derived from 2010 and 2015 yields. Yield data was measured in tonnes and m3 across specific coupes (Ha). Confidence in data is high. Firewood yield data from NSW Forest Corp was defined by tonne and m3 within different harvesting areas in Koondrook-Perricoota forests. Yield data from Victorian Department of Jobs, Precincts and Regions was averaged and contains some uncertainty. Estimates can be improved with finer scale collection of firewood yield data within the harvested coupes that identifies go and no go areas, especially within NSW forestry coupes. '–' = 0

Source: Data from Victorian Department of Jobs, Precincts and Regions (2021) and FCNSW (2021)

Table 31 Biomass for firewood monetary supply and use summary table, GKP, 2010 and 2015

		Economic units			Ecosystem type											
					Gunbower						Koondrook-Perricoota					
Supply/ Use	**Units**	**Household**	**Government**	**Industries**	**Fire-intolerant *Callitris* woodlands**	**Inland floodplain eucalypt forests and woodlands**	**Wetlands**	**Cultivated areas**	**Re-sprouter temperate and subtropical eucalypt**	**Lowland Streams**	**Fire-intolerant *Callitris* woodlands**	**Inland floodplain eucalypt forests and woodlands**	**Wetlands**	**Cultivated areas**	**Re-sprouter temperate and subtropical eucalypt**	**Lowland Streams**
2010																
Supply	$ AUD				-	96,000		-	-	-	-	1,386,000		-	-	-
Use	$ AUD			1,482,000												
2015																
Supply	$ AUD				-	43,000		-	-	-	-	1,116,000		-	-	-
Use	$ AUD			1,159,000												

Note: Residual rents of biomass for firewood are derived from 2010 and 2015 royalty estimates and are presented in nominal terms. Residual rents are the total monetary output less the costs of firewood harvest and depreciation. Confidence in estimates is high. Firewood royalties have been adjusted based on evidence from Victorian Department of Jobs, Precincts and Regions and New South Wales Department of Primary Industries. Yield values from Gunbower forest include some uncertainty and are averages across the thinned region (Ha). Estimates can be improved with finer scale collection of firewood yield and related variable and fixed cost data. '–' = 0

Source: Data from Victorian Department of Jobs, Precincts and Regions (2021) and DPI NSW Department of Primary Industries (2017)

6.4 Floral resources for honey

The GKP ecosystem provides floral resources that support the production of Honey as a service. Honey production is based on the service provided by European Honey bees (*Apis mellifera*) introduced to Australia from Europe in 1822. This service is quantified as the volume and quality of honey from the Gunbower, Perricoota and Koondrook forests. The direct user of this ecosystem service are local Victorian and NSW apiarists who place hives in the GKP ecosystem when it flowers sufficiently. Apiarists benefit from any improvement in the condition of the forest that increases abundance or duration of flowering events and therefore increases the honey yields and health of their hives. Figure 23 shows the relationship between the ecosystem service and humans.

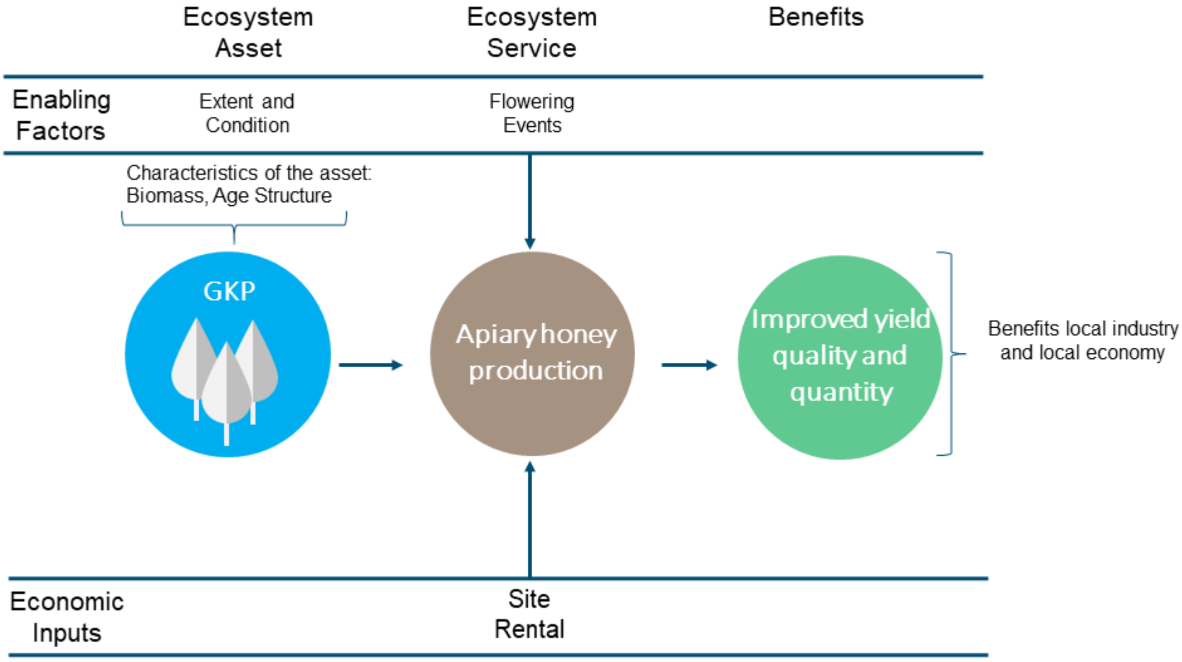
The main transaction of interest in this context is the relationship between the GKP ecosystem and apiarists. The GKP ecosystem provides floral resources for honey as a biotic asset. Access rights to use this biotic asset are allocated by the government (in the form of accessible sites to place hives) which are reflected in the ecosystem services step as 'site rental' (Figure 23).

Flowering events enable the GKP to provide honey for apiarists with access. Apiary is a migratory industry and apiarists only place their hives on sites to produce honey when the floral resources in the surrounding forest (flowering events) are sufficient. *Eucalyptus camaldulensis* (River red gum) typically have a large flowering event every two years. Consultation with local apiarists suggests that River red gums in the GKP ecosystem sustained a two-year flowering pattern up until the year 2000. Local beekeepers report that flowering events have not been as large or regular in Gunbower, Koondrook and Perricoota forests since 2000. Flowering events large enough to produce honey did not occur in 2010 or 2015.

There are other relationships that are not captured explicitly in Figure 23 but are important to consider. River red gums are highly regarded for their ability to support and sustain bee hives. When river red gums flower properly, they produce large amounts of pollen within a short two month window, December-January. This large quantity of pollen facilitates honey production and allows the bees to build their supplementary food stores within the hive. This supports the survival of the hives throughout the rest of the year, especially when they are placed within forests that produce less pollen. River red gums are also well known in the apiary industry for producing high quality pollen. The quality of pollen is important for bee health, longevity and productivity. Management and use of the GKP ecosystem for biomass for timber, firewood and recreation all act as potential pressures on the Apiary industry. Tree harvesting reduces the supply of floral resources available and management burns disrupt hive placements. The link between the ecosystem (quantity and quality), the biomass (quantity and quality), and the transactions are key components of the narrative. The quantity and quality of the assets can affect the quantity of all transactions both now and into the future.

A complete information set will capture each activity or transaction, estimate the potential value of those transactions, and link them to an ecosystem asset to understand how the attributes and condition of the ecosystem affects the transaction. Government can contribute to the set of information outlined in Figure 23 to support the ongoing management of the GKP ecosystem.

Figure 23 Floral resources for Honey



6.4.1 Method

Physical and monetary ecosystem service accounts were explored in this analysis. The biodiversity data outlines in the previous chapters was integrated and informed the ecosystem service accounts. A summary of the method for the physical supply and use is provided in Box 8 and a summary of the method for the monetary supply and use is provided in Box 9. Detailed methods for both ecosystem service accounts are outlined in the technical report (Cheesman et al., 2021). All datasets relied on for the analysis of ecosystem services are referenced at the bottom of the account tables.

Box 8 Approach to producing physical ecosystem service accounts

The physical ecosystem accounts for floral resources for honey calculate the supply of honey from the GKP ecosystem within the target years. The valuation of physical ecosystem service accounts for floral resources for honey is as follows:

- Apiary licence sites were identified within GKP forests. Licenced sites were considered to be the same in both years. The boundaries of the services within the GKP were determined using spatial data from Department of Environment Land, Water and Planning and FCNSW.
- For all licensed areas vegetation characteristics were identified. This included consideration of ecosystem states dominated by river red gum their extent and condition. The influence of environmental water on the vegetation condition was assessed.
- Finally, the provision of honey to the apiary industry from floral resources in the GKP was quantified.
- This structured approach incorporated significant amounts of on-ground ecological survey data from CSIRO and yield data from VF/FCNSW to ensure that the physical ecosystem service accounts closely reflect reality.

Note: The approach is explained in full in the accompanying technical report
Source: Cheesman et al. (2021)

Box 1: Approach to producing monetary ecosystem service accounts

The monetary ecosystem accounts for floral resources for honey calculate the exchange value of the ecosystem services determined under the physical ecosystem accounts. The ecosystem provision service of floral resources for honey can be valued by applying a residual rent dollar value to each tonne of honey yield in 2010 and 2015 respectively. This relationship is represented by:

$$\$ES_{h,y,i,t,e} = H_{y,i,t,z} * RR_{y,i,t}$$

Where:

$\$ES_{h,y,i,t,e}$ is the value of the honey harvest (h), in year (y), at geographic location (i), ecosystem type (t), measured as an exchange value (e)

$H_{y,i,t,z}$ is the honey yield (boxes) in year (y) from geographic location (i), ecosystem type (t) for quality (z)

$RR_{y,i,t}$ is the per unit (box) residual rent from honey in year (y) from location (i) from ecosystem type (t).

A general description of how monetary ecosystem accounts for floral resources for honey were produced is outlined below:

- The floral resources supplied by the GKP ecosystem and the honey harvested by the apiary industry was interrogated. This approach is described in the physical ecosystem accounts in Box 7.
- The residual rents approach is used to determine the exchange value of the supply of floral resources for honey. Resource residual rent of honey harvested from the GKP ecosystem is the output price of honey less the input costs and depreciation costs. Importantly, resource rent is not the revenue from the sales exchange, nor the gross operating surplus. These valuations will overstate the residual resource rent attributable to the biomass for timber and are not directly comparable to the methods and valuations for GKP as a result. The exchange based residual rents approach is covered in detail in the technical report (Cheesman et al., 2021).
- The residual rents per unit of honey supply is multiplied by the physical supply units to determine the exchange value. This process identifies the exchange value for honey on the competitive market. There is a chance that consumers assign a premium to native honey sourced from the GKP ecosystem and are willing to pay more for it in a competitive market. This would be captured as a welfare value. In principle, the two prices will collapse onto each other if we are operating in a competitive market. This follows the basic principle that supply equals demand and should ensure that this analysis fully captures consumer surplus.

Note: The approach is explained in full in the accompanying technical report
Source: Cheesman et al. (2021)

The methods used to define the physical and monetary ecosystem accounts for honey are consistent with or extend methods used or proposed in Australian EEA and natural capital assessments.

6.4.2 Areas for improvement

Access to data was a significant limitation in the analysis of annual floral resources and the resulting honey yield from the GKP ecosystems. No central database of apiarists that place hives in the GKP ecosystem was available from either VF or FCNSW. Similarly, no official record of honey yield from the Gunbower and Koondrook-Perricoota forests is maintained. As a result, the flowering events and annual honey yields from the GKP ecosystem relied on reports from individual apiarists that are known to place hives in the area. Government departments and organisations consulted with include, but is not limited to, the Victorian Department of

Environment, Land, Water and Planning (DELWP), VF, Victorian North Eastern Apiary Association (NEAA), New South Wales Apiary Association (NSWAA), FCNSW.

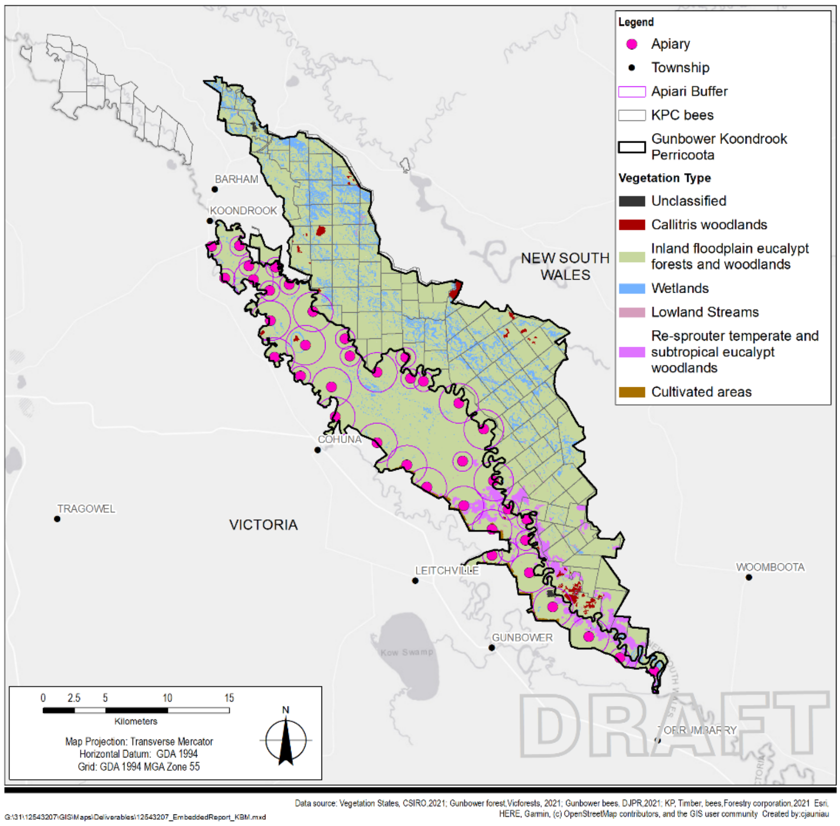
6.4.3 Accounting outputs

A honey physical supply and use table (Table 32) and monetary supply and use table (Table 33) was developed for the accounting area. Supply and use tables show the relationship between floral resources for honey supplied, the GKP ecosystem, and the industry as the user.

Since 2000, local apiarist report that flowering events in the GKP ecosystem have not been as large or as frequent as they were in the decades prior. Prior to 2000, local apiarists report that river red gums in the GKP forests flowered on an approximately two-year cycle. Since 2000, a large flowering event had not occurred in the GKP until the 2020/21 season. Apiarists have been taking their hives elsewhere to produce honey. The 2015 physical supply and use (Table 32) and monetary supply and use (Table 33) tables are empty to reflect that no flowering events occurred in 2010 or 2015 and apiarists could not utilise the resource.

The lack of flowering events are based primarily on the lower flows and extended dry period experienced in the area. For honey production to be profitable apiarists require flowering events of sufficient magnitude and duration for placement of hives. Apiarists also indicated the primary target areas for set down of hives are along the Murray River channel and local water tables are higher.

Figure 24 Apiary licence areas in Gunbower and Koondrook-Perricoota forests



Source: Ecosystem types (Richards et al. 2021a, 2021b), Gunbower Forestry compartments Open data DATA VIC, KP licence areas FCNSW, OpenStreetMap

Table 32. Floral resources for Honey physical supply and use table, GKP, 2010 and 2015

		Economic units			Ecosystem type											
					Gunbower						Koondrook-Perricoota					
Supply/ Use	Units	Household	Government	Industries	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams
2010																
Supply	kg				-	-	-	-	-	-	-	-	-		-	-
Use	kg			-												
2015																
Supply	kg				-	-	-	-	-	-	-	-	-		-	-
Use	kg			-												

Note: Supply and use of floral resources for honey was derived from extensive consultation with apiarists known to place hives in the GKP ecosystem. The location of apiary sites within the GKP ecosystem was provided by VF (G) and FCNSW (KP). There are around 140 sites available for apiarists to place hives on across the Gunbower-Koondrook-Perricoota forests. The consulted apiarist were renting the rights to access at least 40 of these sites across the GKP ecosystems in 2010 and 2015. This represent a significant proportion of the apiary sites available for rent in the GKP ecosystem and demonstrates the extent of stakeholder consultation. Confidence in data is moderate. Estimates can be improved with systematic collection of honey yield data based on site ownership data held by FCNSW and VF. '–' = 0
Source: Data from FCNSW (2021), VF (2021) stakeholder consultation

Table 33. Floral resources for Honey monetary supply and use summary table, GKP, 2010 and 2015

		Economic units			Ecosystem type											
					Gunbower						Koondrook--Perricoota					
Supply/ Use	**Units**	**Household**	**Government**	**Industries**	**Fire-intolerant *Callitris* woodlands**	**Inland floodplain eucalypt forests and woodlands**	**Wetlands**	**Cultivated areas**	**Re-sprouter temperate and subtropical eucalypt woodlands**	**Lowland Streams**	**Fire-intolerant *Callitris* woodlands**	**Inland floodplain eucalypt forests and woodlands**	**Wetlands**	**Cultivated areas**	**Re-sprouter temperate and subtropical eucalypt woodlands**	**Lowland Streams**
2010																
Supply	$ AUD				-	-	-	-	-	-	-	-	-		-	-
Use	$ AUD			-												
2015																
Supply	$ AUD				-	-	-	-	-	-	-	-	-	-	-	-
Use	$ AUD			-												

Note: Monetary supply and use from floral resources for honey are derived from residual rent estimates in 2010 and 2015 and are presented in real terms ($AUD 2020/21). Residual rents are the total monetary output less the costs of honey harvest and depreciation. Confidence in estimates is moderate. Honey royalties were derived from extensive consultation with apiarists known to place hives in the GKP ecosystem. There are around 140 sites available for apiarists to place hives on across the Gunbower and Koondrook-Perricoota forests. The consulted apiarist were renting the rights to access at least 40 of these sites across the GKP ecosystems in 2010 and 2015. This represent a significant proportion of the apiary sites available for rent in the GKP ecosystem and demonstrates the extent of stakeholder consultation. Estimates of exchange value of honey yield can be improved with official recording of annual yields, sale price and harvest cost data. '–' = 0

Source: Data from FCNSW (2021), VF (2021) stakeholder consultation

6.5 Global climate regulation services - carbon sequestration and carbon stocks

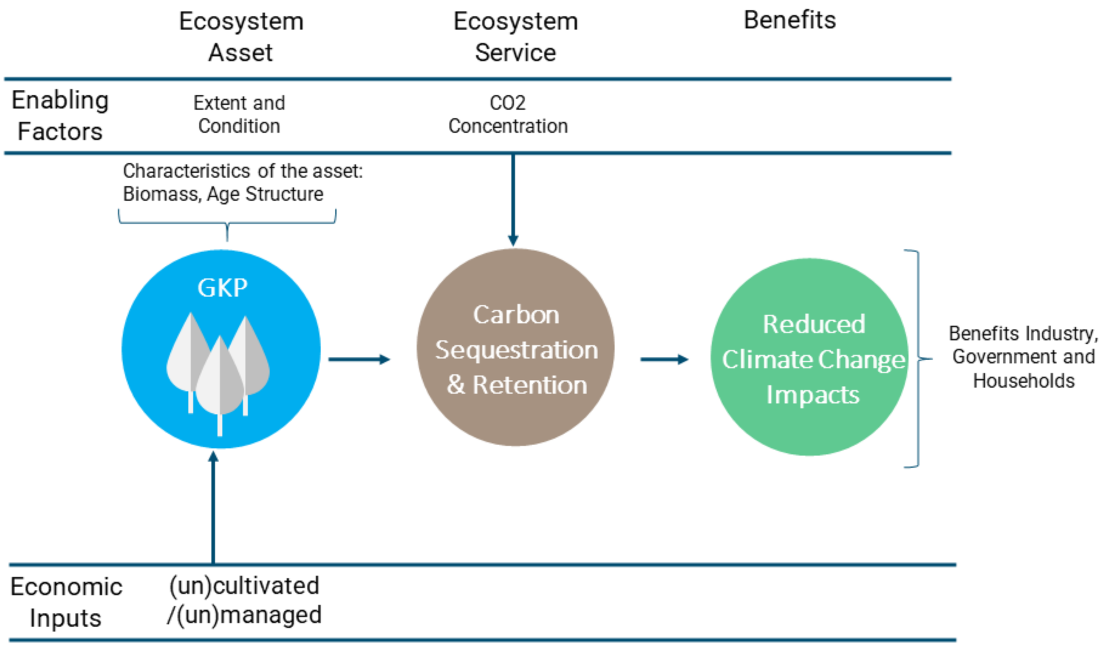
The GKP ecosystem provides global climate regulation services through carbon sequestration and the retention of carbon stocks. This service can be quantified in terms of the tonnes of carbon sequestered per year and the tonnes of carbon retained in biomass in the Gunbower and Koondrook-Perricoota forests. Following the SEEA EA, the user of global climate regulation services is the national government, who are treated as using the service on behalf of the Australian and global communities who benefit from the reduced impacts of climate change.

As shown in Figure 25, the GKP ecosystem sequesters and retains carbon in biomass . Simplistically, the volume of carbon that the GKP ecosystem can sequester from the atmosphere and retain is a function of the carbon dioxide levels in the atmosphere, and the extent and condition of the biotic components within the GKP ecosystem.

There are other relationships that are not captured explicitly in Figure 25 but are important to consider in the management of carbon sequestration and retention within the GKP ecosystem. Mature trees that global climate regulation services are also an asset for species within the forest ecosystem and contribute to the user experience (for example, camping). Timber and firewood harvesting, and coupe management activities like undergrowth clearing and burning are all likely to act as pressures on the GKP ecosystem's ability to sequester and retain carbon. The link between the ecosystem (quantity and quality), the biomass (quantity and quality), and management are key components of the narrative.

A complete information set will capture each activity or transaction, estimate the value of those transactions, and link them to an ecosystem asset to understand how the attributes and condition of the ecosystem affect the transaction. Government can contribute to the set of information outlined in Figure 25 to support the ongoing management of the GKP ecosystem.

Figure 25 Carbon sequestration and retention



6.5.1 Method

Measuring and reporting global climate regulation services within the SEEA EA framework is an ongoing area of research and testing although a clear set of principles has been articulated. In this analysis, physical and monetary ecosystem service accounts were compiled only for the carbon sequestration component of the global climate regulation service, where carbon sequestration is defined as the flow of carbon from the atmosphere into carbon stocks within the GKP ecosystem. Beyond measurement of ecosystem services, measures of the carbon stock within the GKP ecosystem are important for policy and management decision making and hence these are presented in Table 34 to supplement the analysis.

A particular focus was to integrate the account-ready extent and condition data outlined in the previous chapters, characterising measures of carbon sequestration and carbon stock by the different habitat types identified across the study area. A summary of the method for the physical supply and use is provided in Box 9 and a summary of the exchange value of the monetary supply and use is provided in Box 10. The welfare value of the monetary supply and use sits outside the ecosystem accounts and is outlined separately in Box 11. Detailed methods for both ecosystem service accounts are outlined in the technical report (Cheesman et al. 2021). All datasets relied on for the analysis of ecosystem services are referenced at the bottom of the account tables.

Box 9 Approach to producing physical ecosystem service accounts

The physical ecosystem accounts for calculating carbon sequestration and carbon stocks calculate the supply of the ecosystem service. The valuation of physical ecosystem service accounts for carbon sequestration is as follows:

- The spatial area of carbon sequestration and was defined within the boundaries of GKP. This included all ecosystem states present within the GKP.
- Characteristics of the ecosystem state and expression providing the sequestration services were identified for both Gunbower and Koondrook-Perricoota. The extent of services covered both terrestrial and wetland vegetation.
- FullCAM (public release version 2020) was used to calculate carbon sequestration for ecosystem types including inland floodplain Eucalypt forests and woodlands, *Callitris*, black box. FullCAM default above ground biomass for GKP are much lower than identified from site vegetation monitoring. To more accurately reflect the knowledge of vegetation at GKP, FullCAM default settings were adjusted using vegetation expression characteristics data provided by CSIRO (Prober et al. 2021) and discussions with DISER (Tim Liersch, pers comm). Estimates were made for above and below ground living and dead biomass. Soil carbon was not included. Wetland sequestration estimates were based on a state-wide assessment of wetlands in Victoria (Carnell et al. 2018) and other literature sources.
- Mass of carbon sequestration was estimated based on area occupied by ecosystem expressions in 2015.
- Finally, the provision of carbon sequestration to the Government from GKP was quantified.
- This structured approach incorporated significant amounts of on-ground ecological survey data from CSIRO and yield data from VF/FCNSW to ensure that the physical ecosystem service accounts closely reflect reality.

Note: The approach is explained in full in the accompanying technical report
Source: Cheesman et al. (2021)

Box 10 Approach to producing monetary ecosystem service accounts (exchange value)

The monetary ecosystem accounts for carbon sequestration calculate the exchange value of the sequestered carbon. Note that the value of carbon retention is not included in this analysis. The welfare value of carbon sequestration is also calculated for comparison and is outlined separately in Box 12. The ecosystem provision service of carbon sequestration can be valued by applying an exchange value to each tonne of carbon dioxide equivalent (CO2e) sequestered in 2010 and 2015 respectively. This relationship is represented by:

$$\$ES_{c,y,i,t,e} = C_{y,i,t} * 3.664 * EVC_y$$

Where:

$\$ES_{c,y,i,t,e}$ is the value of the carbon sequestration service (c), in year (y), at geographic location (i), ecosystem type (t), measured as an exchange (e) value

$C_{y,i,t}$ is the carbon tonne from the service in year (y) from location (i)

3.664 is the conversion from carbon to CO2e

$EVC_{y,}$ is the exchange value of carbon in year (y). This analysis used two exchange values of carbon, the weighted average Australian Carbon Credit Unit price (Australian Government Clean Energy Regulator, 2021) for year y and the median price of carbon on international markets in year (y), as reported on the World Bank Carbon Pricing Dashboard (The World Bank, 2021).

A general description of how the monetary ecosystem accounts for carbon sequestration were produced is outlined below:

- The carbon supplied to government by the GKP ecosystem was interrogated. This is summarised in the physical ecosystem accounts described in Box 9.
- The exchange value approach was used to value carbon sequestration within the GKP ecosystem. There are a variety of exchange values available for carbon. Carbon pricing represents the idea that to achieve a reduction in carbon, the carbon price should be equal to the marginal abatement cost (MAC) in the accounting period, i.e. the cost of reducing carbon emissions by one unit (Stern 2008). In schemes where there is a cap on the quantity of emissions and where market forces determine the carbon price (for example, in an emissions trading scheme), the observed carbon price represents the marginal private abatement cost to producers of carbon emissions, and hence, the marginal private benefit of sequestering carbon.
- In this analysis, two exchange values were used. The first was the weighted average of ACCUs in year (y) within the Commonwealth's Emissions Reduction Fund. The second exchange value used was the median price of carbon from international markets in year (y) as reported on the World Bank Carbon Pricing Dashboard.
- The relevant price for carbon sequestration supply was multiplied by the physical supply units to determine the exchange value.

Note: The approach is explained in full in the accompanying technical report
Source: Cheesman et al. (2021)

The monetary estimates are calculated using two independent exchange prices of carbon sequestration. This is because Australia does not have an explicit price on carbon. The first calculation relies on the sale prices of Australian Carbon Credit Units (ACCUs) within the Commonwealth's Emissions Reduction Fund. Each ACCU represents one tonne of carbon dioxide equivalent (CO2e) that is stored or avoided by a project. The second exchange value of carbon sequestration relies on the median price of existing international carbon market values. These are reported on the World Bank Carbon Pricing Dashboard data (The World Bank 2021). The World Bank Global median carbon exchange price is preferred for carbon valuation as these values reflect prices for carbon based on observed market transactions. Market prices provide an accurate exchange value of carbon and allow more reliable calculation of the resulting benefit to local, national and global beneficiaries. In comparison, the ACCU exchange value is derived from the funding awarded to projects by the Commonwealth's Emissions Reduction Fund. The weighted average price of ACCU's purchased represents a proxy for carbon prices in Australia but does not explicitly represent an exchange value. If policy analysis required use of an Australian exchange value in the creation of Environmental Economic Accounts, the ACCU value could be relied on as an approximate estimate of $/t CO2e.

The welfare value of carbon sequestration was also calculated for comparison. The welfare value is not a direct exchange and, as a result, sits separate from the ecosystem physical and monetary supply and use tables. The welfare value is presented here to demonstrate the potential gap between the value the market currently places on carbon sequestration and the benefits available from carbon sequestration for society. This is important because the market for carbon sequestration, and the exchange values they produce, are heavily influenced by political sentiment. In comparison, the contemporary literature modelling welfare values attempts to calculate the social cost of carbon from a scientific basis.

It is important to note that modelling of the social cost of carbon is highly sensitive to the assumptions made, including discount rate, damage functions, population with-standing, and uncertainty. Because the amount of damage caused by each incremental unit of carbon in the atmosphere depends on the concentration of atmospheric carbon today and in the future, the social cost of carbon (SCC) varies according to the emissions and concentration trajectory the world is on (Department of Energy and Climate Change 2009). A significant limitation of the SCC modelling relied on for this analysis is a failure to account for the impacts of exceeding environmental tipping points. Exceeding environmental tipping points is expected to cause abrupt and irreversible damages with large market and non-market impacts (Cai et al. 2015). SCC modelling that does not include the risk of environmental tipping points is likely to underestimate the true SCC (Cai et al. 2015; Department of Energy and Climate Change 2009).

Box 11 Approach to producing the welfare value of carbon sequestration

The welfare value of carbon sequestration can be valued by applying the SCC to each tonne of carbon dioxide equivalent (CO2e) sequestered in 2010 and 2015 respectively. The SCC represents the economic value of the damage caused by the emission of a marginal tonne of carbon into the atmosphere. This relationship is represented by:

One tonne of carbon is equal to 3.664 tonnes of CO2e (Department of the Environment and Energy 2020). Such that:

$$\$ES_{c,y,i,t,w} = C_{y,i,t} * 3.664 * SCC_{y,}$$

Where:

$\$ES_{c,y,i,t,w}$ is the value of the carbon sequestration service (c), in year (y), at geographic location (i), ecosystem type (t), measured as a welfare (w) value

$C_{y,i,t,}$ is the carbon tonne from the service in year (y) from location (i), ecosystem type (t)

3.664 is the conversion from carbon to CO2e

$SCC_{y,}$ is the social cost of carbon (SCC) for year (y).

A general description of how the welfare value of carbon sequestration was produced is outlined below:

- The carbon supplied by the GKP ecosystem was interrogated. This is summarised in the physical ecosystem accounts described in Box 10.
- The welfare value approach focuses on valuing the economic and social damages arising from changes in weather patterns and associated natural disasters that can be associated with carbon emissions. In contrast to the carbon price (exchange value), this non-market valuation method represents the marginal social cost of producing carbon emissions or the marginal social benefit (avoided costs) of sequestering carbon (IDEEA Group 2018). The social cost of carbon based welfare value approach is covered in detail in the technical report (Cheesman et al. 2021).
- The estimates of SCC for 2010 and 2015 under a modelled scenario of 2.5% discount rate were applied in this analysis. We adopted the EPA discount rate of 2.5%, in line with the recommended discount rates for low-risk infrastructure from the Victorian government (*Economic Evaluation for Business Cases Technical Guidelines*, 2013). We note that this is lower than the current recommended treasury rate of +/- 7%, however, this is an area of active debate in parliament (Deans 2018). Additionally, this approach reflects the current view of environmental economic accounting, which encourages assets viewed over the long term to have lower discount rates. For completeness, this report incorporates discount rates of 4% and 7% in the ecosystem asset valuation (Chapter 7) as a sensitivity analysis.
- The SCC per tonne of carbon sequestered is multiplied by the physical supply units to determine the welfare value. There is a large range of modelled SCC in the relevant academic literature, this analysis relies on the SCC calculated by the United States Environmental Protection Agency (EPA) in 2016.

Note: The approach is explained in full in the accompanying technical report
Source: Cheesman et al. (2021)

6.5.2 Areas for improvement

Additional research can focus on improving the understanding of carbon sequestration and retention within the GKP ecosystem and the various ways these components of the global climate regulation service can be impacted. The influence that soil health and soil moisture has on carbon sequestration is a particular point of interest for future research. The carbon sequestration estimates included above and below ground living and dead biomass, but soil carbon was not included in the accounts and should be included in future iterations. Understanding these dependencies will contribute to improved AusEcoModel state and transition conceptual models.

Analysis of carbon sequestration within GKP relied on contemporary literature and modelling using FullCAM software. It is recognised FullCAM default values for GKP are lower than that identified through site based ecological monitoring programs. Additional information on vegetation characteristics that could be used to populate FullCAM at the site scale would help refine the estimates. Consideration of carbon losses from decay and succession processes would help with the accounts.

Changes in ecosystem condition (2010 and 2015) are based on changes to ecosystem types. Areas identified as ‘inland eucalypt forests and woodlands’ when inundated through natural or environmental watering events will be identified as ‘wetlands’. Carbon calculation in methods do not reliably account for this difference. This is an areas for further work.

Carbon calculations for wetlands were based on average values (Carnell et al. 2018) taken from amalgamation of a state-wide survey of Victorian wetlands. Averages are highly variable and confirmation of values for GKP would require an extensive sampling program.

6.5.3 Accounting outputs

Carbon stock measures

In 2010 carbon stocks in Gunbower forest varies across the landscape with an estimated 1,796,913 tonnes in Inland floodplain eucalypt forest and woodland, 87,774 tonnes in wetlands, 89,529 tonnes in Re-sprouter temperate and subtropical eucalypt woodlands and 3,783 tonnes in Fire-intolerant *Callitris* woodland (Table 34). In Koondrook-Perricoota carbon stocks are higher with an estimated 3,011,656 tonnes in Inland floodplain eucalypt forest and woodland, 466,428 tonnes in wetlands, 83,663 in Re-sprouter temperate and subtropical eucalypt woodlands and 55,171 tonnes in Fire-intolerant *Callitris* woodland (Table 34).

In 2015, carbon stocks in Gunbower ecosystem types were estimated at 1,943,499 tonnes for inland floodplain eucalypt forest and woodland, 89,698 tonnes in Re-sprouter temperate and subtropical eucalypt woodlands, 75,539 tonnes for wetlands and 3783 tonnes for Fire tolerant *Callitris* woodlands (Table 34). In Koondrook-Perricoota ecosystem types, carbon stocks were estimated at 2,919,186 tonnes for inland floodplain eucalypt forest and woodland, 558,872 tonnes for wetlands, 83,825 tonnes in Re-sprouter temperate and subtropical eucalypt woodlands, and 56,675 tonnes for Fire tolerant *Callitris* woodlands (Table 34).

Accumulation in carbon stock due to growth was assessed using FullCAM for the period 1990 to 2020. Modelling of carbon accumulation identified increased carbon stocks in Gunbower for Inland Eucalypt floodplain forests and woodlands and Re-sprouter temperate and subtropical eucalypt woodlands (Table 35). Carbon stocks in Koondrook-Perricoota increased between 2010 and 2015 for wetlands, Re-sprouter temperate and subtropical eucalypt woodlands, and Fire tolerant *Callitris* woodlands.

Reductions in carbon stock in Gunbower occurred only for wetlands reflecting a lower area of semi-permanent wet (low or moderate) condition wetlands. Decreases in carbon stock at Koondrook-Perricoota primarily occurred for Inland Eucalypt floodplain forests and woodlands. This reduction in part will be through timber and firewood harvesting in Koondrook-Perricoota forestry compartments. While forest timber harvesting by area is relatively low (1-3% per annum 2010 and 2015) it does result in a reduction in stocks and hence in sequestered carbon. Incidence of fires as wildfire and prescribed burns is limited in recent history across the entire site and has not influenced carbon stocks.

FullCAM modelling of carbon stocks provided an estimate per hectare for each ecosystem type Carbon stock estimates (per hectare for each ecosystem type) were similar between 2010 and 2015 (Figure 26 and Figure 27). Wetlands and inland floodplain eucalypt forests and woodlands with highest stocks of 648 and 517 tonnes C per hectare respectively.

Table 34 Carbon stock for each ecosystem type in 2010 and 2015

	Units	Gunbower: Fire-intolerant *Callitris* woodlands	Gunbower: Inland floodplain eucalypt forests and woodlands	Gunbower: Wetlands	Gunbower: Cultivated areas	Gunbower: Re-sprouter temperate and subtropical eucalypt	Gunbower: Lowland streams	Koondrook-Perricoota: Fire-intolerant *Callitris* woodlands	Koondrook-Perricoota: Inland floodplain eucalypt forests and woodlands	Koondrook-Perricoota: Wetlands	Koondrook-Perricoota: Cultivated areas	Koondrook-Perricoota: Re-sprouter temperate and subtropical eucalypt	Koondrook-Perricoota: Lowland Streams
2010	tonnes C	3783	1796913	87774	9	89529	-	55171	3011656	466428	4	83663	-
2015	tonnes C	3783	1943499	75539	9	89698	-	56675	2919186	558872	5	83824	-
change	tonnes C	-	146586	-12235	-	169	-	1504	-92471	92444	1	161	-

Ecosystem type

Note: '–' = 0 Changes in carbon stock for ecosystem types calculated

Table 35 Carbon stock estimates per ha of ecosystem types at GKP. Units stock carbon tonnes /Ha and sequestration tonne carbon /Ha/yr Terrestrial estimates from FullCAM and wetlands based on estimates from Carnell et al. (2018)

Ecosystem service	Units	Gunbower: Fire-intolerant *Callitris* woodlands	Gunbower: Inland floodplain eucalypt forests and woodlands	Gunbower: Wetlands	Gunbower: Cultivated areas	Gunbower: Re-sprouter temperate and subtropical eucalypt woodlands	Gunbower: Lowland Streams	Koondrook-Perricoota: Fire-intolerant *Callitris* woodlands	Koondrook-Perricoota: Inland floodplain eucalypt forests and woodlands	Koondrook-Perricoota: Wetlands	Koondrook-Perricoota: Cultivated areas	Koondrook-Perricoota: Re-sprouter temperate and subtropical eucalypt woodlands	Koondrook-Perricoota: Lowland Streams
Carbon Stock	tonnes C/ha	104	517	648	0.18	99	-	131	517	648	0.18	88	-
Carbon Sequestration	tonnes C/ha/yr	20	104	6	0.20	20	-	19	105	6	0.20	18	-

Ecosystem type

Note: '–' = 0

Figure 26 Distribution of carbon stock (relative comparison) across ecosystem types at GKP - 2010. (Units tonnes Carbon per ha)

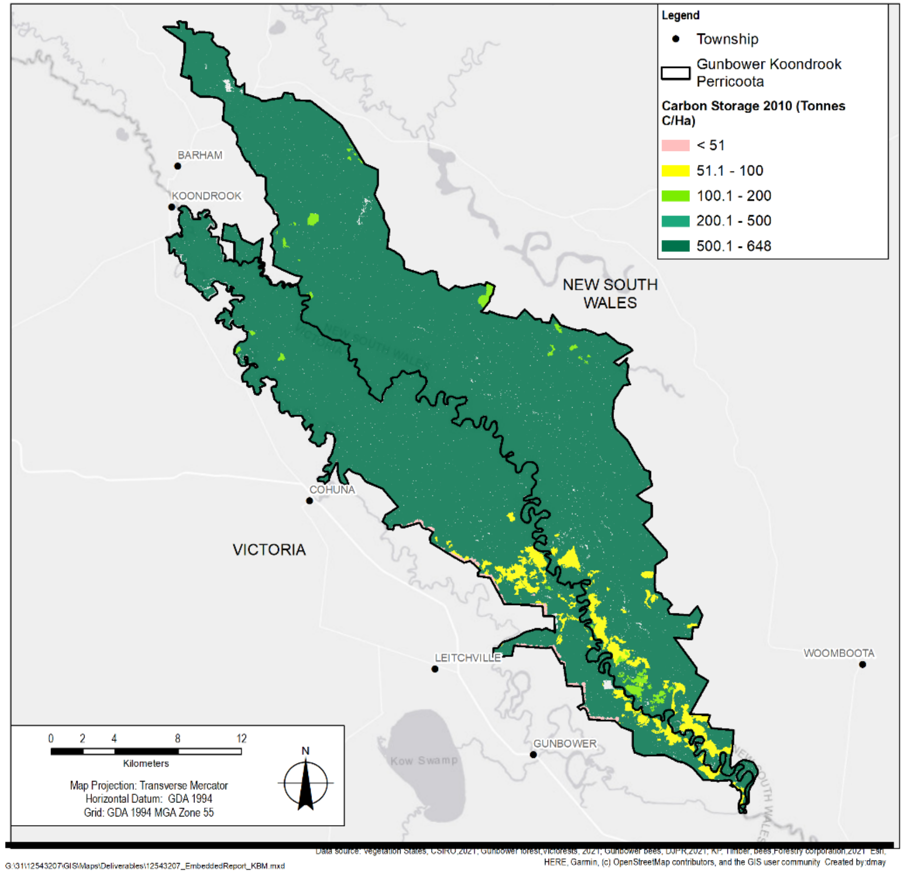
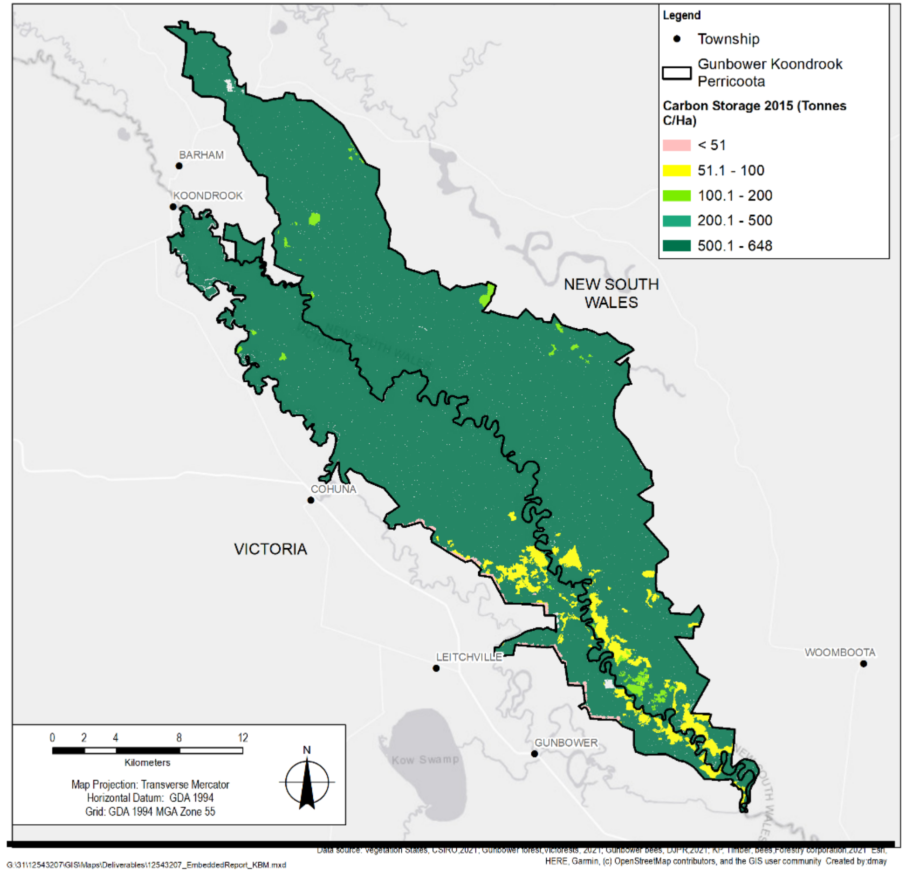


Figure 27 Distribution of carbon stock (relative comparison) across ecosystem types – 2015 (Units tonnes Carbon per ha)



6.5.4 Carbon sequestration physical supply and use

A carbon sequestration physical supply and use table for 2010 and 2015 (Table 36) and monetary supply and use tables for 2010 (Table 37) and 2015 (Table 38) were developed for the accounting area. The physical and monetary supply and use tables show the relationship between carbon sequestration supplied, the GKP ecosystem, and the exchange value provided to the government as the user. The welfare value analysis sits outside the environmental economic accounting framework and is presented separately from the supply and use tables (Table 39). Welfare values rely on the social cost of carbon, instead of the exchange value of carbon, and were calculated for 2010 and 2015.

In 2010, carbon sequestration in Gunbower forest varies across the landscape with an estimated 363,912 tonnes of carbon sequestered in Inland floodplain eucalypt forest and woodland, 18,172 tonnes in Re-sprouter temperate and subtropical eucalypt woodlands, 711 tonnes in Fire tolerant *Callitris* woodlands and 563 tonnes in wetlands (Table 36). In Koondrook-Perricoota carbon sequestration is higher with an estimated 611,370 tonnes in Inland floodplain eucalypt forest and woodland, 3,235 tonnes wetlands, 16,982 in Re-sprouter temperate and subtropical eucalypt woodlands (Table 36). The higher estimates reflect the greater area in Koondrook-Perricoota.

In 2015, carbon sequestration in Gunbower ecosystem types was estimated at 392,019 tonnes for inland floodplain eucalypt forest and woodland, 18,150 tonnes in Re-sprouter temperate and subtropical eucalypt woodlands, 711 tonnes for Fire tolerant *Callitris* woodlands and 512 tonnes for wetlands. For Koondrook-Perricoota ecosystem types, carbon sequestration was estimated at 590,676 tonnes for inland floodplain eucalypt forest and woodland, 16,962 tonnes in Re-sprouter temperate and subtropical eucalypt woodlands, 7,853 tonnes for Fire tolerant *Callitris* woodlands and 3,879 tonnes for wetlands.

Accumulation in carbon stock due to growth was assessed using FullCAM for the period 1990 to 2020. Modelling of carbon sequestration rates identified increased carbon stocks in Gunbower for Inland Eucalypt floodplain forests and woodlands (Table 36). Carbon sequestration rates in Koondrook-Perricoota increased between 2010 and 2015 for wetlands only.

Reductions in carbon sequestration rates in Gunbower occurred only for wetlands and Re-sprouter temperate and subtropical eucalypt woodlands reflecting a lower area of semi permanent wet (low or moderate) condition wetlands. Decreases in carbon stock at Koondrook-Perricoota primarily occurred for Inland Eucalypt floodplain forests and woodlands. This reduction in part will be through timber and firewood harvesting in KP forestry compartments. While forest timber harvesting by area is relatively low (1-3% per annum 2010 and 2015) it does result in a reduction in sequestered and stored carbon.

FullCAM modelling of carbon sequestration provided an estimate per hectare for each ecosystem type. Carbon sequestration estimates for ecosystem types with slight reductions in the northern areas of Koondrook-Perricoota for the ecosystem type Inland floodplain Eucalypt forests and woodlands were similar between 2010 and 2015 (Figure 28 and Figure 29).

Figure 28 2010 carbon sequestration rates for ecosystem types at GKP. (Units tonnes Carbon ha^{-1} yr^{-1})

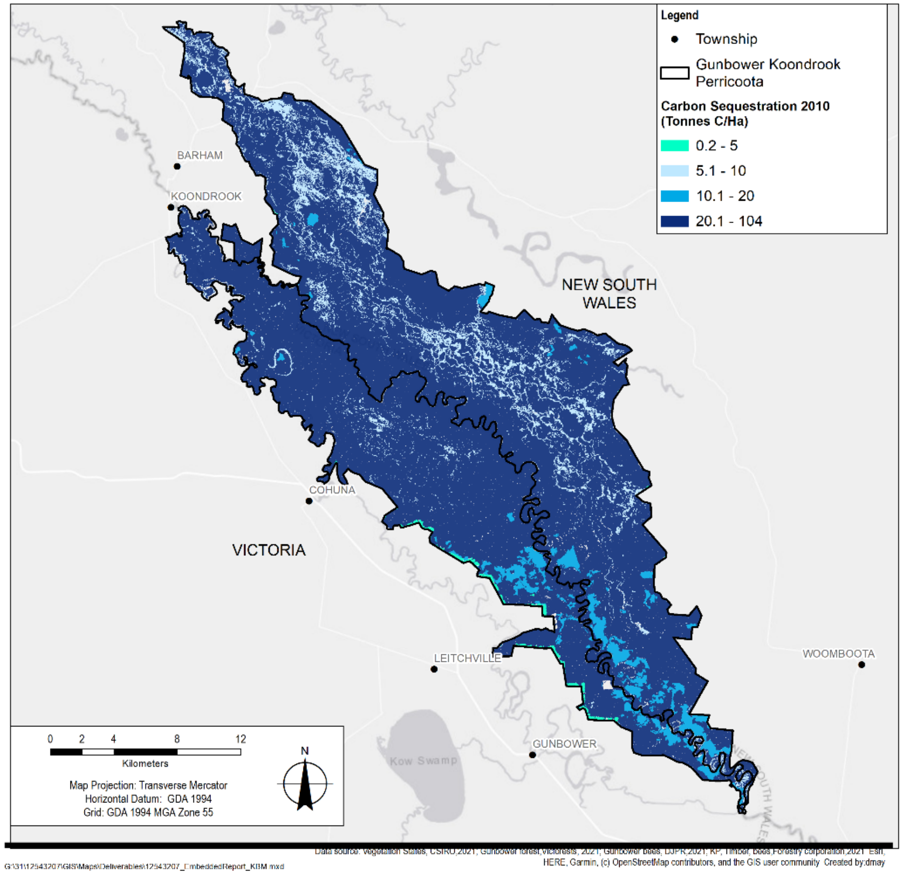
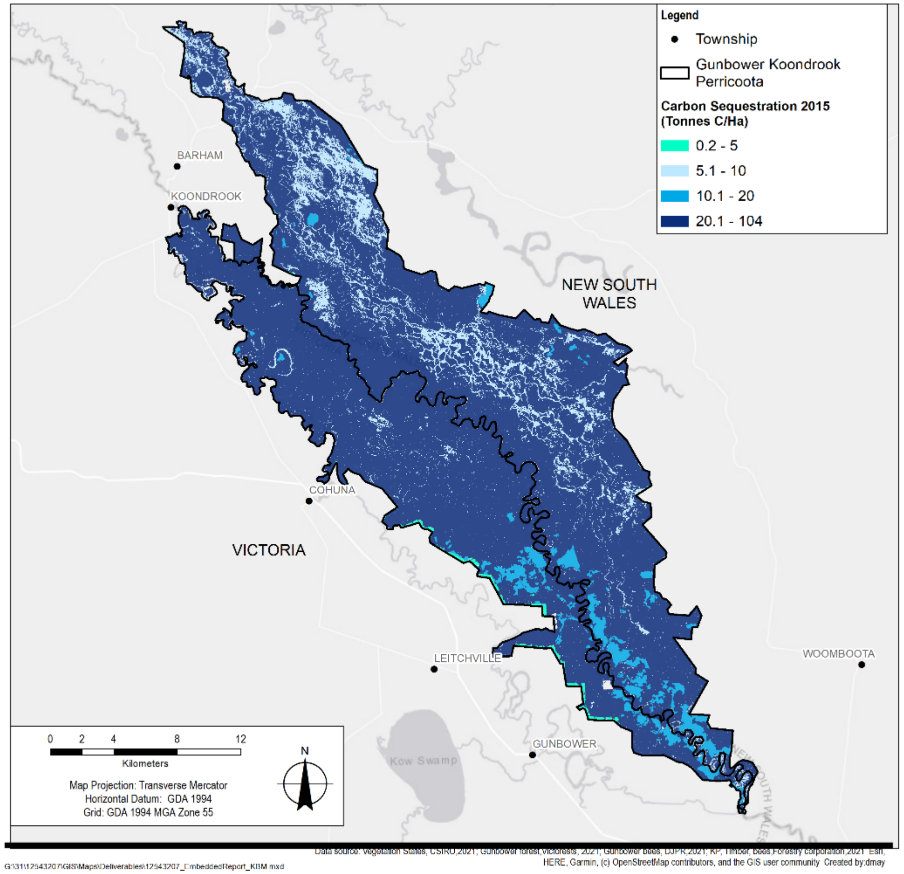


Figure 29 2015 carbon sequestration rates for ecosystem types at GKP. (Units tonnes Carbon ha^{-1} yr^{-1})



Carbon sequestration monetary supply and use

Table 37 outlines the monetary supply and use calculated for carbon sequestration within the GKP ecosystem in 2010. The monetary supply and use calculations rely on the weighted average exchange value of all ACCUs traded within the Commonwealth's Emissions Reduction Fund and the median exchange value of carbon sequestration on international markets in 2010 as recorded on the World Bank Carbon Pricing Dashboard. The total monetary supply and use of carbon sequestration relying on ACCU exchange values was around $48 million. This is compared to the total monetary supply and use of carbon sequestration calculated using the World Bank Carbon Pricing median in 2010 which is around $70.1 million. 'Inland floodplain eucalypt forests and woodlands' supplied around $16.9 million and $28.5 million of monetary supply and use across Gunbower forest and Koondrook-Perricoota forest respectively in 2010 when calculations relied on ACCU exchange values. When calculations relied on the World Bank Exchange values the monetary supply from 'Inland floodplain eucalypt forests and woodlands' was around $25.1 million and $42.1 million from Gunbower and Koondrook-Perricoota forests respectively.

Table 38 outlines the monetary supply and use calculated for carbon sequestration within the GKP ecosystem in 2015. The monetary supply and use calculations rely on the weighted average exchange value of ACCUs traded within the Commonwealth's Emissions Reduction Fund in 2015 and the median exchange value of carbon sequestration on international markets in 2015 as recorded on the World Bank Carbon Pricing Dashboard. The total monetary supply and use of carbon sequestration relying on ACCU exchange values was around $49.4 million. This is compared to the total monetary supply and use of carbon sequestration calculated using the World Bank Carbon Pricing median in 2015 which is around $93.5 million. 'Inland floodplain eucalypt forests and woodlands' supplied around $18.8 million and $28.3 million of monetary supply and use across Gunbower forest and Koondrook-Perricoota forest respectively in 2015 when calculations relied on ACCU exchange values. When calculations relied on the World Bank Exchange values the monetary supply from 'Inland floodplain eucalypt forests and woodlands' was around $35.5 million and $53.6 million from Gunbower and Koondrook-Perricoota forests respectively.

Table 39 outlines the welfare value of carbon sequestration and sits outside the traditional System of Environmental Economic Accounting (SEEA) framework. The welfare value is presented in this analysis as a comparison to the exchange values in the monetary supply and use table for carbon sequestration (Table 37 and Table 38) and are valued using the SCC calculated by the US EPA (2016). The SCC represents the economic value of the damage caused by the emission of a marginal tonne of carbon into the atmosphere. In 2010 the total welfare value of carbon sequestration from the GKP ecosystem was around $246 million. In 2015 this total is estimated at around $311 million. 'Inland floodplain eucalypt forests and woodlands' supplied around $87 million and $147 million of welfare value across Gunbower forest and Koondrook-Perricoota forest respectively in 2010. In 2015 the welfare value supplied by the 'Inland floodplain eucalypt forests and woodlands' rose to around $118 million and $178 million from the Gunbower forest and Koondrook-Perricoota forest, respectively.

Table 36 Carbon sequestration physical supply and use table, GKP, 2010 and 2015

Supply /Use	Units	Economic units			Ecosystem type											
					Gunbower						Koondrook-Perricoota					
		Household	Government	Industries	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland streams	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams
2010																
Supply	tonnes				711	363,912	563	5	18,172	0	7,854	611,370	3,235	4	16,982	0
Use	tonnes	-	1,022,807	-												
2015																
Supply	tonnes				711	392,019	512	5	18,150	0	7,853	590,676	3,879	5	16,962	0
Use	tonnes	-	1,030,771	-												

Note: Physical supply and use of Carbon sequestration is based on 2010 and 2015 data. Yields data was measured in tonnes of carbon for each ecosystem type. Confidence in data is high. Yield data was provided by CSIRO and complemented by FullCAM modelling. Estimates can be improved with a better understanding of the ecological system and how it sequesters carbon as a whole, , especially the contribution of soil. '–' = 0

Source: Data from FullCAM calculated sequestration and stock values for terrestrial systems and wetland estimates based on Carnell et al. (2018)

Table 37 Carbon sequestration monetary supply and use summary table, GKP, 2010

			Economic units			Ecosystem type											
						Gunbower						Koondrook-Perricoota					
Supply/ Use	Units	Source	Household	Government	Industries	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams
Supply	$ AUD	ACCUs				33,000	16,961,000	26,000	-	847,000	-	366,000	28,495,000	151,000	-	791,000	-
Use	$ AUD	ACCUs		47,670,000													
Supply	$ AUD	WBM				49,000	25,094,000	39,000	-	1,253,000	-	542,000	42,158,000	223,000	-	1,171,000	-
Use	$ AUD	WBM		70,529,000													

Note: Monetary supply and use from carbon sequestration in 2010 is derived from the weighted average exchange value of all historic ACCUs sales in the Commonwealth's Emissions Reduction Fund and the median price (WBM = World Bank Median) of carbon from international markets in 2010 as reported on the World Bank Carbon Pricing Dashboard. A weighted average of the total ACCUs exchange values was used because the Commonwealth's Emissions Reduction Fund was not operational in 2010. The monetary supply and use of carbon sequestration is presented in nominal terms. Confidence in estimates is moderate. Yield values from the GKP ecosystem include some uncertainty and are a function of the best available information involved in FullCAM yield modelling. '–' = 0

Source: Data from FullCAM carbon estimates based on estimates based on Carnell et al. (2018), ACCU exchange values rely on the Commonwealth's Emissions Reduction Fund sale prices of Australian Carbon Credit Units (ACCUs).

Table 38 Carbon sequestration monetary supply and use summary table, GKP, 2015

			Economic units			**Ecosystem type**											
						Gunbower						**Koondrook-Perricoota**					
Supply/ Use	**Units**	**Source**	**Household**	**Government**	**Industries**	**Fire-intolerant *Callitris* woodlands**	**Inland floodplain eucalypt forests and woodlands**	**Wetlands**	**Cultivated areas**	**Re-sprouter temperate and subtropical eucalypt woodlands**	**Lowland Streams**	**Fire-intolerant *Callitris* woodlands**	**Inland floodplain eucalypt forests and woodlands**	**Wetlands**	**Cultivated areas**	**Re-sprouter temperate and subtropical eucalypt woodlands**	**Lowland Streams**
Supply	$ AUD	ACCUs				34,000	18,816,000	25,000	-	871,000	-	377,000	28,352,000	186,000	-	814,100	-
Use	$ AUD	ACCUs		49,475,000													
Supply	$ AUD	WBM				64,000	35,562,000	46,000	-	1,646,000	-	712,000	53,583,000	352,000	-	1,539,000	-
Use	$ AUD	WBM		93,504,000													

Note: Monetary supply and use from carbon sequestration in 2015 is derived from the average 2015 ACCUs sale price in the Commonwealth's Emissions Reduction Fund and the median price (WBM = World Bank Median) of carbon from international markets in 2015, as reported on the World Bank Carbon Pricing Dashboard. The monetary supply and use of carbon sequestration is presented in nominal terms. Confidence in estimates is moderate. Yield values from the GKP ecosystem include some uncertainty and are a function of the best available information involved in FullCAM yield modelling. '–' = 0

Source: Data from FullCAM carbon estimates based on estimates based on Carnell et al. (2018), ACCU exchange values rely on the Commonwealth's Emissions Reduction Fund sale prices of Australian Carbon Credit Units (ACCUs).

Table 39 Carbon sequestration welfare value, GKP, 2010 and 2015

		Economic units			Ecosystem type											
					Gunbower						Koondrook-Perricoota					
Supply/ Use	Units	Household	Government	Industries	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams
2010																
Supply	$ AUD				171,000	87,528,000	135,000	1,000	4,371,000	-	1,889,000	147,046,000	778,000	1,000	4,084,000	-
Use	$ AUD	-	246,004,000	-												
2015																
Supply	$ AUD				215,000	118,508,000	155,000	1,000	5,487,000	-	2,374,000	178,563,000	1,173,000	1,000	5,128,000	-
Use	$ AUD	-	311,605,000	-												

Note: The welfare value of carbon sequestration in 2010 and 2015 is derived from the average United States Environmental Protection Agency (EPA) estimates of the global social cost of carbon sequestration in target years. Welfare value estimates were derived by the EPA in 2016 and are highly conservative. Updated modelling of welfare value estimates including contemporary assumptions would be useful for future analysis. Updated modelling could include market and non-market impacts from environmental tipping points. The welfare values of supply and use of carbon sequestration are presented in nominal terms. Confidence in estimates is moderate. Yield values from the GKP ecosystem include some uncertainty and are a function of the best available information involved in FullCAM yield modelling. '–' = 0

Source: Data from Data from FullCAM carbon estimates based on estimates based on Carnell et al. (2018), welfare value calculations rely on (Interagency Working Group on the Social Cost of Greenhouse Gases 2016).

6.6 Floral resources for hive building

The GKP ecosystem provides floral resources as a service, which apiarists use to build the health and food stores of their hives. Healthy, well-stocked hives provide crop pollination services across Victoria and NSW, contributing to an Australian wide industry that was estimated to return $40 million in revenue in 2019 (Clarke and Le Feuvre 2021). The extent that the GKP ecosystem supports crop pollination as a service is difficult to quantify directly without an accurate understanding of how many trips apiarists took to the Gunbower and Koondrook-Perricoota forests to build or rest their hives in the target years. Instead, the qualitative value of the GKP ecosystem to the apiary industry is discussed. The direct users of this ecosystem service are local Victorian and NSW apiarists who place hives in the GKP ecosystem. Apiarists benefit from any improvement in the condition of the forest that increases abundance or duration of flowering events and therefore increases the health of their colonies and the food stores within their hives. Figure 30 shows the relationship between the ecosystem service and humans.

The main transaction of interest in this context is the relationship between the GKP ecosystem and apiarists. The GKP ecosystem provides floral resources for hive building as a biotic asset. Access rights to use this biotic asset are allocated by the government (in the form of accessible sites to place hives) which are reflected in the ecosystem services step as 'site rental' (Figure 30).

Apiary is a migratory industry and apiarists plan their hive placement 18 months in advance based on rainfall and environmental watering and flooding events. Hives are placed when the floral resources in the surrounding forest (flowering events) are sufficient. Floral resources in the GKP ecosystem are predominately provided by river red gum and black box eucalypts. *Eucalyptus camaldulensis* (River red gum) typically have a large flowering event every two years. Consultation with local beekeepers suggest that river red gums in the GKP ecosystem sustained a two-year flowering pattern up until the year 2000. Local beekeepers report that flowering events have not been as large or regular in Gunbower-Koondrook-Perricoota forests since 2000. Flowering events large enough to produce honey did not occur in 2010 or 2015.

Table 40 Intermediate services flowering events

Flowering event	Red gum	Black box
Flowering frequency (years)	2 (1-8)	2 (1-5)
Flowering period	Summer	Depending on the location flowers observed in all months except February and March during 2004-2006 on the lower Murray floodplain (Jensen et al. 2008a). (response to water availability)
Nectar production quantity (tins)	0.5-3.0	0.5-2.0
Nectar production frequency (years)	2-11+	1-10
Age of reproductive maturity (flowering)	20-40 yrs	20-50 yrs

Note Nectar production quantity (tins) (~27kg per tin)

Red gum and black box species commence flowering when they are between 20-50 years old. Maturation (and reproductive output) is influenced by interactions with existing vegetation and may be delayed until natural thinning of pole stage Eucalypts and suppression of weaker or smaller trees has occurred (Smith and Long 2001; George et al. 2005). Tree condition also impacts reproductive output, with healthy trees producing more fruit and shedding larger quantities of seed than those with lower canopy vigour (George et al. 2005). Maximum bud loads (and flowers) are a likely result from their being sufficient water available to support reproduction. Once trees are mature, buds may be retained for up to 12 months before flowering. Under conditions of low rainfall and drought, buds may drop prior to flowering as a strategy to maintain tree health.

Water availability is a critical driver for flowering to occur. Sufficient water in the prior 12 months is the primary driver as flowering itself is relatively independent of rainfall (George 2004, Jensen et al. 2008a. The number of flower buds is affected by water availability (170% increase recorded at one site following a high rainfall period (Jensen et al. 2006, 2008a). Both river red gum and black box trees primarily source water from groundwater, then surface water, then rainfall.

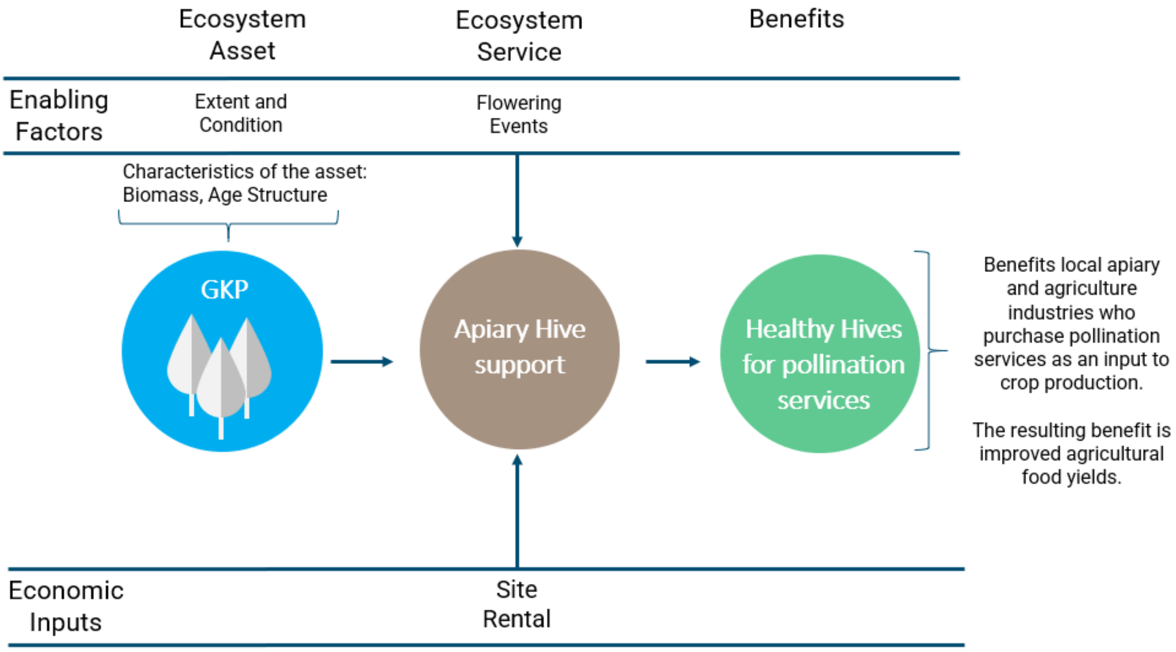
The correct environmental conditions will prompt large scale flowering events involving a majority of the red gum or black box community. Minor flowering events, involving individual trees, still occur under less favourable conditions. These smaller flowering events in the GKP ecosystem are still an important service for the apiary industry and allow apiarists to build the health of their hives. Apiarists transfer their hives over large distances to provide crop pollination services and pursue flowering events for honey production. In the absence of flowering events with large enough floral resources to produce honey, and if there are no crops to pollinate, the hives are rested. Apiarists rest hives in strategic locations to take advantage of minor floral resources in the surrounding ecosystem and continue building the health and food stores of their colonies. While local beekeepers report that flowering events large enough to produce honey did not occur in the GKP forests in 2010 or 2015, a proportion of apiarists surveyed still rested their hives on sites within Gunbower and Koondrook-Perricoota forests.

There are other relationships that are not captured explicitly in Figure 30 but are important to consider. *Eucalyptus camaldulensis* (River red gum) forests are highly regarded for their ability to support and sustain bee hives. River red gums are well known in the apiary industry for producing high quality pollen. The quality of pollen is important for bee health, longevity and productivity. Hives that are healthy and well stocked with pollen are necessary when providing crop pollinating services.

Management and use of the GKP ecosystem for biomass for timber, firewood and recreation all act as potential additional pressures on the apiary industry. Tree harvesting reduces the supply of floral resources available and management burns disrupt hive placements. The link between the ecosystem (quantity and quality), the biomass (quantity and quality), and the transactions are key components of the narrative. The quantity and quality of the assets can affect the quantity of all transactions both now and into the future.

A complete information set will capture each activity or transaction, estimate the potential value of those transactions, and link them to an ecosystem asset to understand how the attributes and condition of the ecosystem affects the transaction. Government can contribute to the set of information outlined in Figure 30 to support the ongoing management of the GKP ecosystem.

Figure 30 Floral resources for hive building



6.6.1 Method

The GKP ecosystem contributes floral resources to the Victorian and NSW apiary industry as a service. Apiarists rely on these floral resources to build the food stores of their hives before providing crop pollination services. The value of the GKP ecosystem to crop pollination can be discussed in terms of the number of pollinators it supports, the quality of the support it provides and the economic value of the pollination services it enables. The migratory nature of the apiary industry means that all floral resources available across NSW and VIC are important for the provision of crop pollination services. This analysis therefore discusses the crop pollination industry in Victoria and NSW as a whole, instead of attempting to attribute a share of the industry to the GKP ecosystem. A more detailed understanding of how apiarists utilise the GKP ecosystem to build their hives in the presence of low floral resources (such as those provided in 2010 and 2015) would be necessary to attribute a share of the pollination industry to the GKP ecosystem.

Floral resources provided by the GKP ecosystem have the potential to support a substantial proportion of Australia's crop pollination industry. Importantly, the GKP ecosystem is located on the border of NSW and Victoria, which are both key states for apiary in Australia. The majority of Australia's beekeepers and beehives are located in NSW and Victoria. 60% of Australia's beekeepers and 63% of Australia's beehives were based across NSW and Victoria in 2019 (Clarke and Le Feuvre 2021). As a result, a significant proportion of Australia's commercial crop pollination services are provided across NSW and Victoria. In 2015, the Australian pollination industry consisted of an estimated 520,000 hives and returned around $24.9 million to recreational and commercial beekeepers. Of these 520,000 hives, around 30% were available for pollination services in Victoria and 40% were available in NSW (Clarke and Le Feuvre 2021).

The GKP ecosystem provides high quality floral resources to support the crop pollination industry. The GKP ecosystem consists of large *Eucalyptus camaldulensis* (river red gum) forests that are highly regarded for their ability to support and sustain beehives. River red gums produce high quality pollen important for bee health, longevity and productivity. Hives that are healthy and well stocked with pollen are necessary when providing crop pollinating services. Different crops provide different amounts of sustenance to the bee colony (Clarke and Le Feuvre 2021). If apiarists are pollinating crops that provide the bees with minor amounts of pollen, the existing food stores within the hives must sustain the colony. This reinforces the importance of resting hives in ecosystems that can provide high quality food stores to the colony to support them in the future. Healthy, well-stocked hives provide crop pollination services without the need for supplementary feeding from apiarists. This reduces the market and non-market costs borne by the Apiary industry.

To the extent that the GKP ecosystem supports the crop pollination industry in Victoria and NSW, it has the potential to provide significant value to the economy. Several studies have analysed the economic value of the Australian honeybee pollinating industry. Recent work by John Karsinski (2018) estimated that in 2015 the economic value of Australian honey bees was around $14 billion, based on two empirical price elasticities of demand coefficients for fresh fruit and vegetables (Krasinski 2018). An average of $6.1 billion of the total economic value originated from pollination in Victoria and $2.5 billion from pollination activity in NSW (Krasinski 2018).

6.6.2 Areas for improvement

A limitation of the analysis above is that recreational apiarists and commercial apiarists with less than 50 hives were not included in the analysis of Australia's pollination industry. This means estimates of commercial and recreational pollinator numbers across Australia are likely understated. Similarly, it is understood that apiarists often register their hives in multiple states because of the migratory nature of the industry. This means some hives are likely to be double counted.

Additional research should focus on improving the central collection and open access to apiary data across NSW and Victoria. This could allow future analysis to attribute a portion of the crop pollination industry to the GKP ecosystem. We understand that FCNSW is in the process of registering all beekeepers and their hives online, in an attempt to record how they utilise forest ecosystems. This information, and information from a similar system in Victoria, would significantly enhance the power of future analysis.

6.7 Ecosystem and species appreciation

The GKP ecosystem provides habitat for a wide range of species (including birds, mammals, fish, frogs and reptiles) that support flows of non-use values to people. These flows are treated as complementary valuations within the SEEA standard. Complementary values are defined as a flow related to non-use values, in this case, the flow is ecosystem and species appreciation. It is important to note that ecosystem and species appreciation has been presented here as an exchange value, where the SEEA standard exclusively discusses non-use values as welfare values. As the exchange value of ecosystem and species appreciation value is non-use, it is considered separately to the other exchange values presented in this report.

Flows have been quantified as the area of habitat for 8 focal species that are listed as species of national environmental significance under the *Environment Protection and Biodiversity Conservation Act 1999* and in the Ecological Character Description for Gunbower and Koondrook-Perricoota Ramsar sites. The 8 focal species include Australasian bittern, painted honeyeater, superb parrot, growling grass frog, koala, rigid spider-orchid, winged pepper-cress, river swamp wallaby-grass within the boundaries of GKP.

It is important to emphasise that the 8 focal species are a subset of the total number of species in GKP. This means the accounting estimates presented in this section only relate to the subset of 8 focal species. The direct user of the flows from these 8 focal species are Australian households; however, as endemic and endangered Australian species, the beneficiary population could extend beyond local communities and Australian households. People overseas may place a non-use value on Australia's native wildlife.

Data about these species is also relevant in managing and conserving the GKP ecosystems. Maintaining habitat is essential for species during their breeding or non-breeding season. Inclusion of habitat in management priorities for species protection is recognised as a critical component for persistence of species (Mott et al. 2020, Brundrett 2016).

Figure 31 shows the relationship between ecosystem and species appreciation and benefits for the 8 focal species (as a subset of all species) within the boundaries of GKP.

Habitat for the 8 focal species has been identified drawing on the CSIRO species-level biodiversity assessments (see Chapter 8 and Mokany et al. 2021a, 2021b). The biodiversity assessment used estimates of the original spatial distribution for each focal species from the Species of National Environmental Significance database (Mokany et al. 2021a). Suitable habitat for focal species was determined spatially by allocating land cover attributes representative of their broad habitat preference (Mokany et al. 2021a).

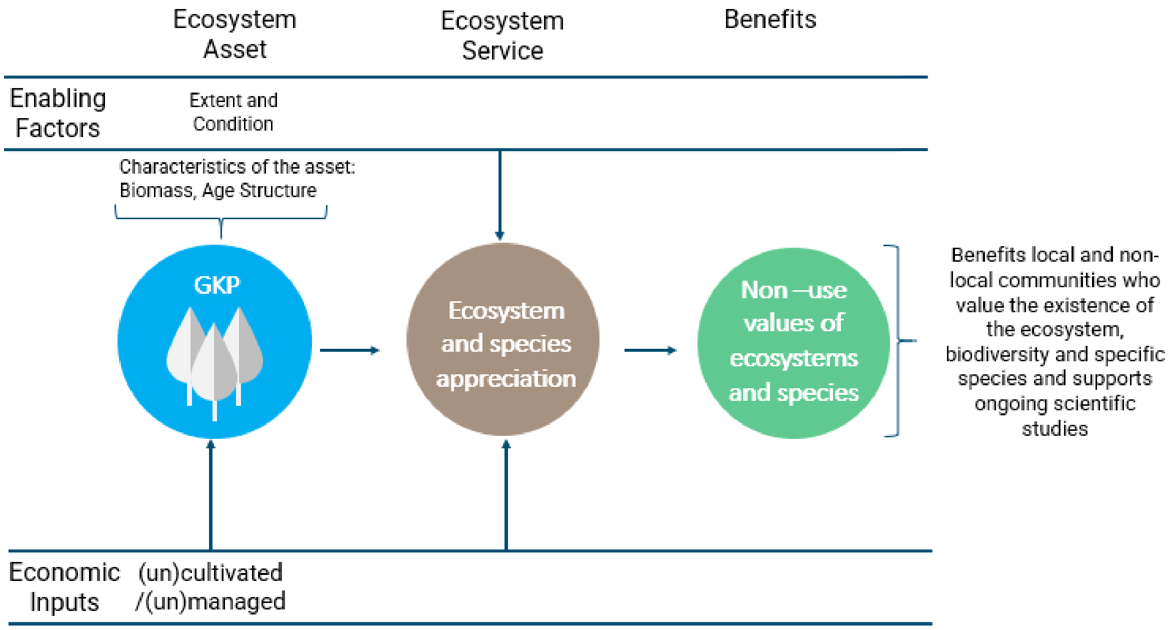
Presence of suitable habitat based on the CSIRO modelling indicates the habitat is considered suitable to support the focal species. It does not indicate these species are actually present. As such, the accounting estimates for species are based on habtat proxies. The proxy approach based on habitat hectares was used in the GKP because data on species abundance and distribution in GKP was not available.

There are other relationships that are not captured explicitly in Figure 31 but are important to consider in site management. The suitability of habitat is likely to be influenced by natural and endogenous events. The ecosystem services provided by habitat are also likely to benefit other species or contribute to user experience (for example, camping). More broadly biodiversity at

GKP is a critical asset for maintaining the capacity of ecosystems and ecosystem complexes to deliver goods and services into the future (King et al. 2017). The link between the ecosystem (extent and condition) of habitat reflects the underlying capacity of the system to continue to support ecosystem and species appreciation supply.

A complete information set will capture each activity or transaction, estimate the value of those transactions, and link them to an ecosystem asset to understand how the attributes and condition of the ecosystem affects the transaction. Government can contribute to the set of information outlined in Figure 31 to support the ongoing management of the GKP ecosystem, for example through regulation and requiring offsets.

Figure 31 Ecosystem and species appreciation – 8 focus species



6.7.1 Method

Physical and monetary flows of ecosystem and species appreciation were produced in this analysis. A focus was to integrate the account-ready biodiversity data (Mokany et al. 2021b) outlined elsewhere in this report (Chapter 8). A summary of the method for the physical flows is provided in Box 12 and a summary of the method for the monetary flows is provided in Box 13. Detailed methods are outlined in the technical report (Cheesman et al. 2021). All datasets relied on for the analysis of these flows are referenced at the bottom of the account tables.

Box 12 Approach to producing physical flow accounts

The physical flow accounts for ecosystem and species appreciation for the 8 focal species record the supply of these flows. The estimation of physical flow accounts for habitat involved:

- Spatial assessment in GKP identified 2010 and 2015 habitat for 8 focal species (as a subset of total species in GKP; Mokany et al. 2021a).
- Ecosystem service characteristics are defined based on assessed areas of habitat in GKP for 8 focal species. CSIRO biodiversity data provided individual data sets for 10 focal species. The assessment process identified areas of suitable habitat (ecosystem types) in 2010 and 2015 for the 10 focal species as a subset of all species at GKP. The assessment does not indicate presence of these species

only suitable habitat. Defining the areas of suitable habitat supporting two or more focal species is a proxy that aligns with habitat hectares. Habitat hectares was used in the GKP because data on species abundance and distribution was not readily available from the CSIRO work. Additionally, this analysis excludes two of the focal species included in the CSIRO work, black box and river red gum, because they are highly abundant across the GKP area. Inclusion of black box and river red gum species in the analysis would have skewed results.

- Based on the assessment of suitable habitat across 8 focal species, areas of ecosystem types have been calculated to quantify the ecosystem service. This provides the basis for quantifying the provision of ecosystem services of habitat to moral wellbeing and knowledge of the environment in GKP. The physical supply was also developed to quantify the habitat values for monetary valuation. This reflects a habitat valuation approach analogous to habitat hectares.
- The spatial area included all ecosystem types across GKP.
- Ecosystem service characteristics were defined for each ecosystem type based on CSIRO spatial data sets for ecosystem extent and condition in 2010 and 2015 (Richards et al. 2021a). To provide a relative habitat value score, spatial extents for each ecosystem type were adjusted reflecting condition at each data point.
- Habitat value was then quantified across GKP.

Note: The approach is explained in full in the accompanying technical report
Source: Cheesman et al. (2021)

Box 13 Approach to producing monetary ecosystem service accounts – 8 focus species

The monetary ecosystem accounts for ecosystem species and appreciate calculate the proxy exchange value of the non-use values of ecosystems and species (8 focus species are included in the analysis) provided in 2010 and 2015 respectively. This relationship is represented by:

$$\$ES_{s,y,i,t,wm} = \sum_{s,y,i,t} \left(H_{s,y,i,t} * P_{s,y,i,t,}\right)$$

Where:

$\$ES_{s,y,i,t,wm}$ is the non-use values of ecosystems and species, measured as the value of the habitat required to support a species (s), in year (y), at geographic location (i), ecosystem type (t), measured using observed biodiversity offset market trades

$H_{s,y,i,t}$ is the habitat in hectares required to support (s) in year (y) from location (i), ecosystem type (t)

$P_{s,y,i,t,}$ is the annuity equivalent biodiversity market price for habitat hectares in year (y) from location (i), ecosystem type (t). The annuity price converts the capitalised offset price into annual payments to be consistent with the annual accounting stance for ecosystem service supply.

$\sum_{s,y,i,t}$ shows that the total value is the sum of total hectare payment requirements.

A general description of how the monetary ecosystem accounts for habitat were produced is outlined below:

- The habitat supplied to households by the GKP ecosystem was interrogated. This is summarised in the physical ecosystem accounts described in Box 15.
- The exchange value approach was used to value habitat within the GKP ecosystem. There are a variety of exchange values available for habitat hectares for biodiversity conservation. For Victoria, The Victorian Native Vegetation Credit Trade Register (DELWP 2021) was interrogated to calculated volume weighted average prices (VWAP) for Habitat Hectares ($VWAPHH), by EVC for offsets

registered in 2010 and 2015 respectively. Habitat hectares are a combined measure of condition and extent of native vegetation (DELWP, 2021).

- The $VWAPHH by EVC for were converted into hectare equivalents. This was done by estimating habitable hectares supplied by the GKP ecosystem for each EVC based on the quality of the raster data. Estimates were developed using EnSym.
- The relevant price for $VWAPHH supply by EVC for 2010 and 2015 was converted to an annuity, using the same timeframe (into perpetuity) and discount rate (2.5%) assumptions as those used to for ecosystem asset valuation (Chapter 7). This provided annual exchange values for 2010 and 2015 habitat supply. These values are conceptually the same as annual rents for habitat supply.
- The annual rents for habitat supply by EVC was multiplied by the physical supply units to determine the exchange value.

Note: The approach is explained in full in the accompanying technical report
Source: (Cheesman et al., 2021)

6.7.2 Areas for improvement

This assessment has been based on 8 focal species. These species are a subset of all species present in GKP. The quantification and valuation are only for the 8 species and cannot be scaled to include all species at GKP.

The assessment quantifies suitable habitat for species, but this does not indicate presence of these species. This suitable habitat proxy approach has been used in this example as data on the abundance and distribution of the 8 focal species was not available through CSIRO modelling or other work.

The quantification of species appreciation services relies on a number of strong assumptions including that (1) the species are present in the habitat areas identified as suitable for the species (2) there is an approximate positive relationship between the presence of species and the quality of the hectares used as proxy for species presence, such that increasing the quality of hectares is likely to increase the presence and abundance of the 8 focal species (3) the $VWAPHH can be used as a proxy for species in the absence of more direct monetary valuation measures for the 8 focal species.

Future research should focus on establishing better linkages between land suitability and species presence in the GKP. This could be done by working collaboratively with agencies undertaking on- ground fish and bird monitoring (Webster 2017). Using an approach based in on-ground monitoring would allow for scaling up of species data using a robust and evidence-based simulation approach.

The use of biodiversity credits for habitat to establish the exchange value of the GKP ecosystem species and appreciation value should only be used as an approximate proxy value if direct species valuation data is not available, either in the form of traded species credits or non-market valuation estimates. For credits to be a perfect proxy, their price would need to be adjusted to offset the difference in ecosystem location between where the credit was originally purchased and the GKP ecosystem that it is being applied to. Additionally, there is potential that additional ecosystem supply from GKP would drive down cost of biodiversity credits in the area. This would mean price adjustments would not be marginal.

Additional research should focus on improving understanding of the demand and welfare values for selected focal species. These demand value functions could then be converted into exchange values for species, potentially by adapting and extending the simulated exchange value method (SEVM) (Badura et al. 2018).

Recent work has looked to establish the economic value of multiple threatened species and ecological communities in Australia (Gunawardena et al. 2020b). If future work in GKP is coordinated, there is an opportunity to link this type of species valuation work with species prevalence assessments in future work. This has not been possible in this assessment as:

Gunawardena et al. (2020b) establishes welfare estimates for only one of the 8 selected focal species evaluated for these accounts by CSIRO – the Australian Bittern.

While the species-level assessments in Mokany et al. (2021) are intended to identify areas of suitable habitat within the potential extent of occurrence of each species, as noted above they do not indicate where each of the 8 species is expected to occur, or the species abundance that is expected to occur. Mokany et al. (2021) note that combined with potential errors in the land cover classification, or in translating land cover categories to habitat suitability, areas of suitable habitat with the potential extent of occurrence may be under- or over-estimated, with the result that the "focal species could vary considerably in terms of both their potential extent of occurrence, as well as the estimated areas of suitable habitat" (Mokany et al. 2021). In practical terms these limitations make it difficult to robustly estimate species abundance in 2010 and 2015 from the simulations.

Other work has recently attempted to quantify bequest and existence values for native waterbird and fish species in northern Victoria (Natural Capital Economics 2019). NCE notes that the estimates are preliminary, based on the analysis approach and assumptions made.

Future work to establish robust and evidence-based welfare values for focal species in GKP and northern Victoria should focus on:

- Establishing better linkages between land suitability and species presence. As discussed above, this could be done by working collaboratively with agencies undertaking on-ground bird and fish monitoring (Natural Capital Economics 2019). This would allow for scaling up of species data using a robust and evidence-based simulation approach.
- Conducting willingness to pay studies for the 8 GKP focal species, potentially by replicating the approach in Gunawardena (2020b).

6.7.3 Accounting outputs

Ecosystem and species appreciation flow tables were compiled in physical terms (Table 41) and exchange value monetary terms (Table 42). Supply and use tables show the relationship between habitat supplied, the GKP ecosystem, and households as the user.

Habitat suitability assessment of Gunbower forest identified a total of 17,062 ha in 2010 suitable for the 8 focal species. This varied across habitats with 15,756 ha Inland floodplain eucalypt forest and woodland, 459 ha of wetlands, 765 ha of Re-sprouter temperate and subtropical eucalypt woodlands 70 ha Lowland streams and 7 ha of Fire-intolerant *Callitris* woodland (Table 41). In Koondrook-Perricoota modelling identified a total of 27,750 ha in 2010 suitable for the 8 focal species. This also varied across habitats with 23,116 ha of Inland floodplain eucalypt forest and woodland, 3,681 ha of wetlands, 814 ha of Re-sprouter temperate and subtropical eucalypt woodlands 60 ha of Lowland Streams and 79 ha of Fire-intolerant *Callitris* woodland (Table 41).

Habitat suitability assessment of Gunbower forest identified a total of 13,938 ha in 2015 suitable forthe 8 focal species. This varied across habitats with 12,817 a Inland floodplain eucalypt forest and woodland, 389 ha of wetlands, 636 ha of Re-sprouter temperate and subtropical eucalypt woodlands 72 ha Lowland streams and 7 ha of Fire-intolerant *Callitris* woodland (Table 41). In Koondrook-Perricoota modelling identified a total of 14,659 ha in 2015 suitable for the 8 focal species. This also varied across habitats with 11,207 ha of Inland floodplain eucalypt forest and woodland, 2,829 ha of wetlands, 562 ha of Re-sprouter temperate and subtropical eucalypt woodlands 41 ha of Lowland Streams and 20 ha of Fire-intolerant *Callitris* woodland (Table 41).

Between 2010 and 2015 there was a reduction in area of modelled suitable habitat for the 8 focal species across GKP (Table 41). The greatest reduction in habitat for these focal species was 11,909 ha from 'inland floodplain eucalypt forests and woodlands' ecosystem type in Koondrook-Perricoota. Other significant reductions in Koondrook-Perricoota include 852 ha wetlands and 252 ha re-sprouter temperate and subtropical eucalypt woodlands. The largest decrease in habitat for the 8 focal species in Gunbower was 2,929 ha from 'inland floodplain eucalypt forests and woodlands' ecosystem type.

The monetary supply and use table (Table 42) presents the exchange values associated with ecosystem and species appreciation in 2010 and 2015. Ecosystem and species appreciation in 2010 has a total exchange value of around $150 million. The 'Inland floodplain eucalypt forests and woodland' ecosystem type provides the largest proportion of value in both 2010 and 2015. In 2010, this ecosystem type provided around $46.5 million of exchange value from Gunbower ecosystem and around $71.2 million from the Koondrook-Perricoota ecosystem. In 2015, the total ecosystem and species appreciation exchange value fell slightly to around $113 million. In 2015, the 'Inland floodplain eucalypt forests and woodland' ecosystem type provided around $30.4 million of exchange value from the Gunbower ecosystem and around $45.2 million from the Koondrook-Perricoota ecosystem.

Figure 32 Areas in GKP identified to provide suitable habitat in 2010 for up to 8 of the focal species

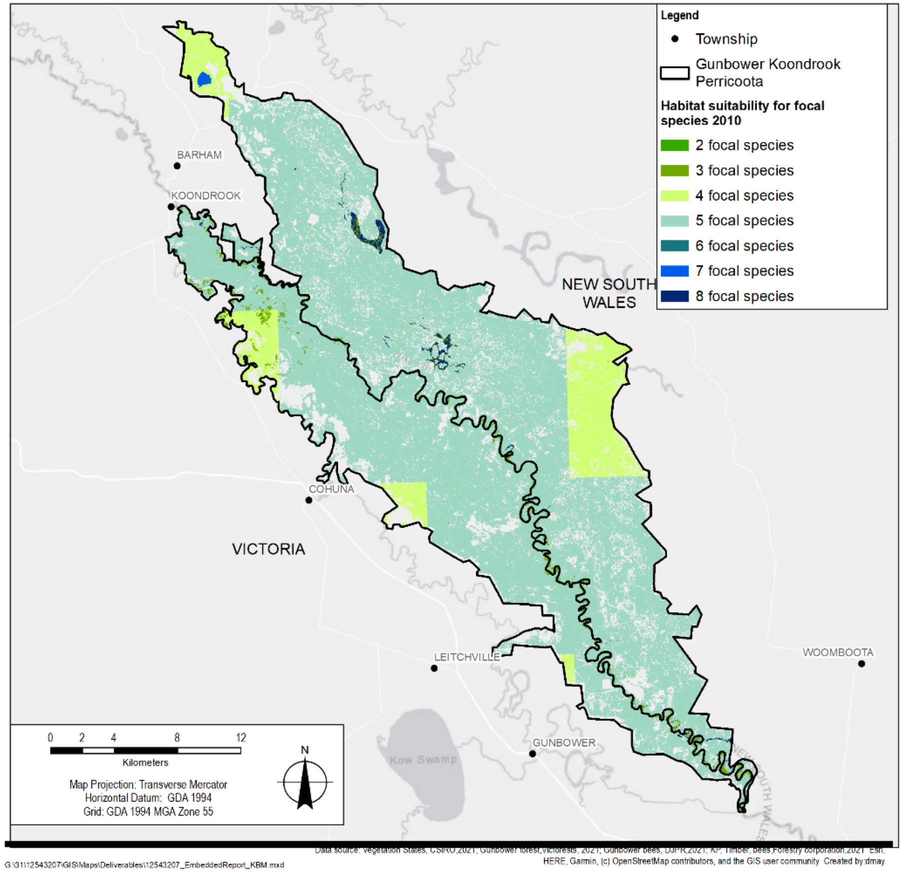


Figure 33 Areas in GKP identified to provide suitable habitat in 2015 for up to 8 of the focal species

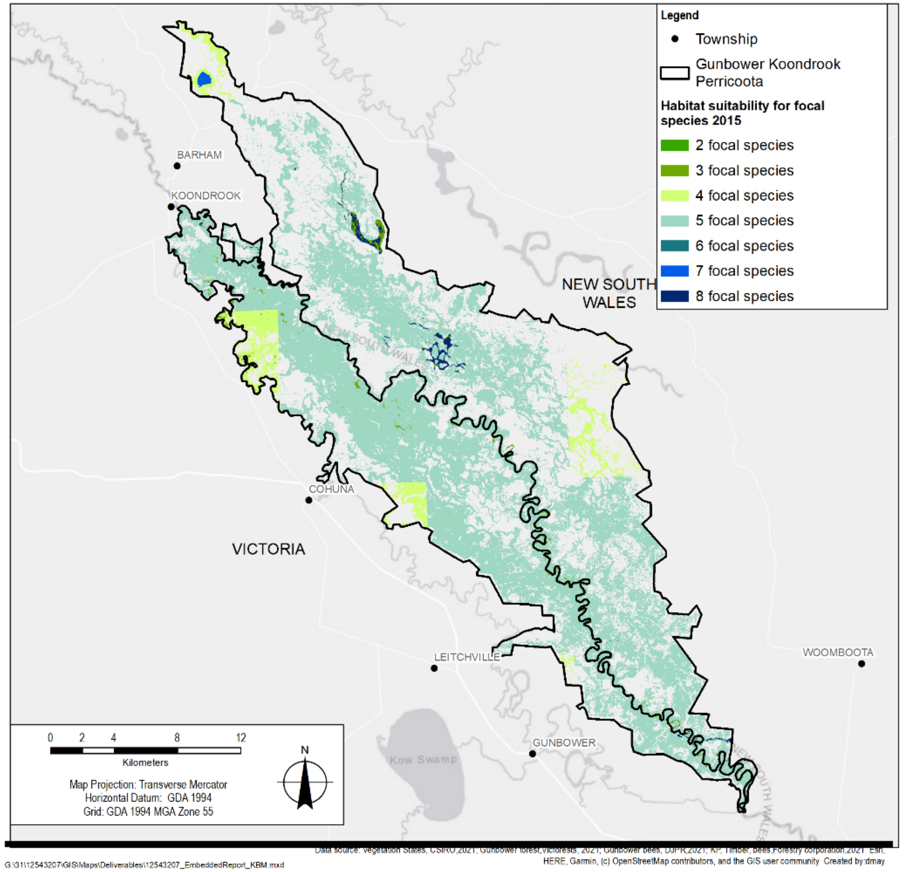


Table 41 Ecosystem and species appreciation physical supply and use table for 8 focal species, GKP, 2010 and 2015

		Economic units			Ecosystem types											
					Gunbower						Koondrook-Perricoota					
Supply / Use	Units	House hold	Government	Industries	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams
2010																
Supply	ha				7	15,756	459	5	765	70	79	23,116	3,681	0	814	60
Use	ha	44,812														
2015																
Supply	ha				5	12,827	389	9	636	72	20	11,207	2,829	-	562	41
Use	ha	28,597														
Change	ha	16,215			-2	-2,929	-70	4	-129	2	-59	-11,909	-852	0	-252	-19

Note: Supply and use of ecosystem and species appreciation is derived from analysis of the GKP ecosystem in 2010 and 2015 yields. Data was measured in ha across the different ecosystem types in Gunbower and Koondrook-Perricoota. Confidence in data is moderate. Estimates can be improved with finer scale collection of ecosystem data and the ecological interactions between species in the region. '–' = 0
Source: Data from Mokany et al. (2021b)

Table 42 Ecosystem and species appreciation monetary supply and use summary table (exchange values) for 8 focal species, GKP, 2010 and 2015

		Economic units			Ecosystem type											
					Gunbower						Koondrook–Perricoota					
Supply/ Use	Units	Household	Government	Industries	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams
2010																
Supply	$ AUD				143,000	46,513,000	3,048,000	-	1,251,000	-	1,645,000	71,205,000	25,344,000	-	1,321,000	-
Use	$ AUD	150,470,000														
2015																
Supply	$ AUD				158,000	30,442,000	2,531,000	-	1,580,000	-	1,823,000	45,147,000	29,471,000	-	1,669,000	-
Use	$ AUD	112,821,000														

Note: The exchange value of ecosystem and species appreciation is derived from estimated habitable hectares of the 8 focal species provided by the GKP ecosystem and are in present value (PV) terms as calculated for 2010 and 2015 respectively. Confidence in estimates is low. Estimates can be improved with finer scale collection of ecosystem data and the ecological interactions between species in the region. '–' = 0

Source: Data from (Mokany et al. 2021b), Victorian Department of Jobs, Precincts and Regions (2021) and DPI NSW (2017)

6.8 Water flow regulation

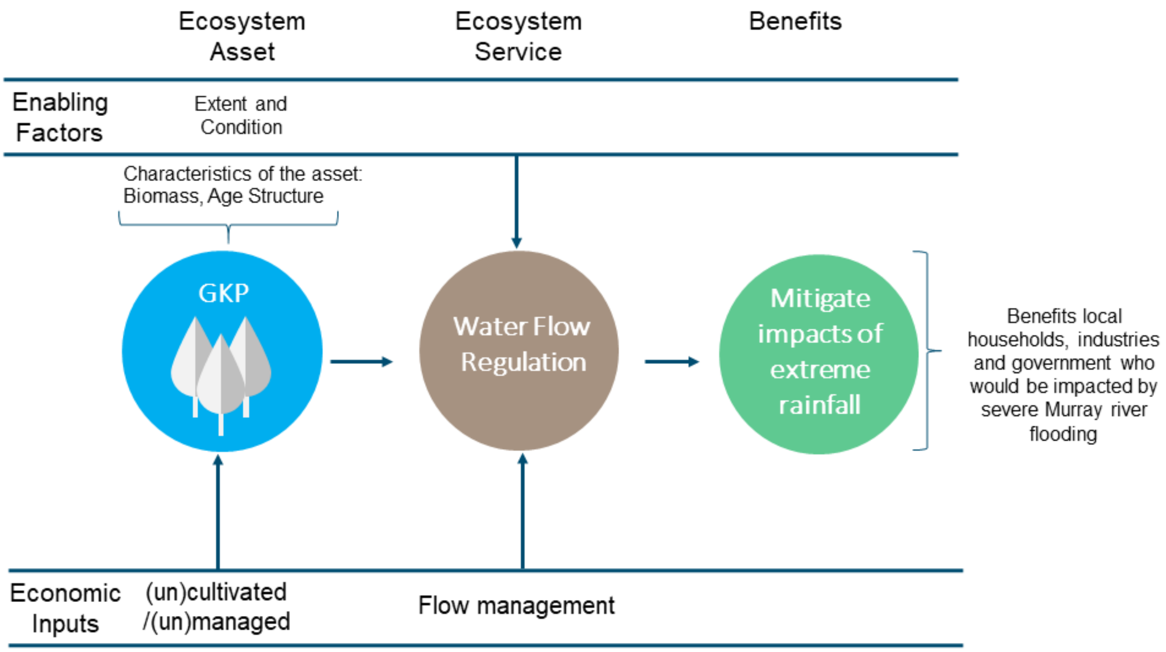
The GKP ecosystem provides water flow regulation as a service to downstream rural and urban communities. This service is quantified as the volume of ecosystem types from the Gunbower- and Koondrook-Perricoota forests under differing flood regimes. The direct user of this ecosystem service are the local communities, which benefits from retention of water in the forest that reduces flooding of private land. Figure 34 shows the relationship between the ecosystem service and users.

The main transaction of interest in this context is the relationship between the GKP ecosystem and rural and urban communities. The GKP ecosystem provides variable water regulation under different flow regimes. Management of the capacity to provide water flow regulation is based on management of flood events in the Murray River and irrigation areas.

There are other relationships that are not captured explicitly in Figure 34 but are important to consider in flow regulation. GKP forests naturally require water annually and for extended periods of time to maintain ecosystem assets. Under the current water entitlements there is insufficient water available to meet ecological requirements of the forest system. Extended flooding events provide significant benefit to the ecosystem and have flow on benefits to other ecosystem services.

A complete information set will capture each activity or transaction, estimate the potential value of those transactions, and link them to an ecosystem asset to understand how the attributes and condition of the ecosystem affects the transaction. Government can contribute to the set of information outlined in (Figure 34) to support the ongoing management of the GKP ecosystem.

Figure 34 Water flow regulation



6.8.1 Method

Options to quantify the physical ecosystem service for water flow regulation were investigated but not quantified. A summary of the approaches and outcomes are provided below. Physical and monetary ecosystem service accounts were not produced in this analysis.

Box 14 Approach to producing physical ecosystem service accounts

The basis for defining flows was to use a counter factual approach where quantification of the service would be based on no floodplain attenuation in GKP and flooding occurring downstream in the vicinity of Barham. The analysis steps included:

- Assess daily flows in 2010-11 at Torrumbarry and Barham gauges, assess likely travel times and calculate differences in flows.
- Review hydrographs to assess correlation with commence to flow thresholds for floodplain effluents and regulators (Shillinglaw and Barham Cut regulators). Review of existing studies (GHD 2009, MDBA 2012c) to confirm flow distribution across GKP and reductions in flows between Torrumbarry and Barham gauges
- Assess flow regulation using counter factual analysis assuming the flows above channel capacity of approximately 30,000 ML do not enter GKP floodplain and there is no reduction in flows between Torrumbarry and Barham. These flows would peak around 50,000 ML per day which are significantly greater than 1:100 and 1:200 year events identified in GHD (2014).

The analysis of flow regulation could only identify the total volume and differences in flood peaks from attenuation of flows in Gunbower and Koondrook-Perricoota forests. Calculation of the area of inundation downstream that could result as a result of no attenuation on the floodplain was not completed as would require specific hydrological modelling runs which were beyond the scope of the investigation.

Note: The approach is explained in full in the accompanying technical report

Source: Cheesman et al. (2021)

Box 15 Approach to producing monetary ecosystem service accounts

The monetary ecosystem accounts water flow regulation calculates exchange values by applying an avoided damage cost to water flow regulation in 2010 and 2015 respectively.

The avoided damage cost reflects the value of the water flow (flooding) damage avoided by GKP. Similar to the replacement costs approach, the focus of the damage cost approach is generally on flow regulation provided by GKP ecosystems that are lost if the ecosystem were not present or in a condition such that the flow regulation service could not be provided.

The water flow regulation service in the accounts reflected avoided flood damage costs.

Water flow regulation values are calculated as the difference in monetary flood damage with GKP overbank flows and without GKP overbank flows. End beneficiaries are industry, households and government who would be impacted by flooding. Such that:

$$\$ES_{d,y,i,t,e} = \sum_{y,i,t} \left(V_{y,i,t} * D\right) * 1.2$$

Where:

$\$ES_{d,y,i,t,e}$ is the total value of direct and indirect damage avoided from GKP floodplain water retention (d), in year (y), at geographic location (i), ecosystem type (t), measured as a total direct and indirect damage (e) value.

$V_{y,i,t}$ is the volume of floodwater captured in floodplain in year (y) by location (i), ecosystem type (t)

$D_{s,y,i,t,}$ is the estimated damage to users, calculated using depth-damage functions and spatial inundation modelling for V, if this floodwater had not been captured.

1.2 is the ratio of direct to indirect damage, discussed below

$\sum_{y,i,t}$ shows that the total damage value is the sum of damage value estimates across ecosystem types and locations, for a given year.

Water flow regulation impacts were assessed for the Barham Floodplain Risk Management Area (BFRMA). A general description of how the exchange value of water flow regulation is outlined below:

- The flooding incidence for BFRMA was interrogated for 2010 and 2015. This is summarised in the physical ecosystem accounts described in Box 14.
- The monetary value of the BFRMA in 2010 and 2015 depends on the likely flooding incidence, extent, duration and impacts. In 2015 there were flooding no events, and hence water flow regulation has a $nil exchange value.
- In 2010 flooding in northern Victoria and in BFRMA would have had different monetary impacts if GKP had not existed and operated to provide water flow regulation services.
- The impact of GKP water flow regulation in BFRMA is calculated using the Rapid Appraisal Methodology (Flood RAM) and revised standard values for RAM (URS 2009).
- Simulation run outputs from the BFRMA were used to prepare stage-damage curves reflecting the relationships between depth and location of flooding and the assigned monetary value of damages. The assigned value of damages is calculated drawing on information detailing the characteristics of the buildings, agricultural enterprises and infrastructure that will be assessed. The assigned value of damages is calculated using information detailing the characteristics of the buildings, agricultural enterprises and infrastructure in the flood impact areas. This includes data such as floor level, building type, size and condition, agricultural land use type and road type.
- To represent floor level inundation in the absence of floor level survey, residential properties were assumed to incur damages when more than 50% of a property is inundated and the depth of flooding is greater than 150 mm.
- To represent inundation in the absence of survey, commercial and industrial properties were assumed to incur damages when more than 33% of a property is inundated and the depth of flooding is greater than 100 mm.
- To represent inundation in the absence of survey, roads were assumed to incur damagers when inundation depth exceeds 300 mm based on (Olesen et al. 2017).
- Standard Values for agriculture were adopted from (URS 2009).
- The damages were based on a cadastral layer and planning scheme data. This includes lots that were not developed in 2010 and were yet to be classified as industrial or residential. This approach results in a conservative estimate of damages; this assumption is consistent with the assumptions in the flood mapping.
- The total area of agricultural land and road length were defined by VICMAP dataset.

Note: The approach is explained in full in the accompanying technical report
Source: Cheesman et al. (2021)

The methods used to define the biomass for water regulation physical and monetary ecosystem accounts are consistent with or extend methods used or proposed in Australian EEA and natural capital assessments.

6.8.2 Areas for improvement

Quantification of water flow regulation of forest areas and wetlands is a complex task and requires access to modelling runs or ability to model scenarios involving floodplain inundation.

In urban and highly populated areas flooding investigations have been conducted assessment of services is likely to be more straight forward. Quantifying the flow regulation ecosystem service will require flood modelling to provide a counter factual assessment which is not a common approach for flood modelling.

Additional research can also focus on improving the central collection and open access to ecosystem supply data. This analysis collated information on the GKP ecosystem provision services from a number of different sources with varying levels of difficulty. A streamlined approach to data resourcing for use in ecosystem accounting should be organised to assist future calculations. This approach should also incorporate residual rents of ecosystem supply to ensure their accuracy. This would give managers a more complete picture of what their ecosystem is providing to different stakeholders and substantially improve their ability to make management decisions.

6.8.3 Accounting outputs

A waterflow physical supply and use table (Table 43) and monetary supply and use table (Table 44) was developed for the accounting area. Supply and use tables show the relationship between waterflow supplied, the GKP ecosystem, and the government as the user. This approach aligns with the SEEA framework.

The 2015 physical supply and use (Table 43) and monetary supply and use (Table 44) tables are empty to reflect that flows in the Murray River at Torrumbarry were below the flow threshold of 13,700ML per day at Shillinglaws regulator during 2015. Apart from the Gunbower environmental watering event, flooding of the forest did not occur in 2015, and GKP did not provide a water regulation service in that year.

Table 43 Waterflow physical supply and use table, GKP, 2015

		Economic units			Ecosystem type											
					Gunbower						Koondrook–Perricoota					
Supply/ Use	**Units**	**Household**	**Government**	**Industries**	**Fire-intolerant *Callitris* woodlands**	**Inland floodplain eucalypt forests and woodlands**	**Wetlands**	**Cultivated areas**	**Re-sprouter temperate and subtropical eucalypt woodlands**	**Lowland Streams**	**Fire-intolerant *Callitris* woodlands**	**Inland floodplain eucalypt forests and woodlands**	**Wetlands**	**Cultivated areas**	**Re-sprouter temperate and subtropical eucalypt woodlands**	**Lowland Streams**
2010																
Supply	ha				-	-	-	-	-	-	-	-	-	-	-	-
Use	ha			-												
2015																
Supply	ha				-	-	-	-	-	-	-	-	-	-	-	-
Use	ha			-												

Note: Physical supply of use of water flow regulation services has not been analysed due to data availability constraints. '–' = 0

Table 44 Waterflow monetary supply and use summary table, GKP, 2015

		Economic units			Ecosystem type											
					Gunbower						Koondrook–Perricoota					
Supply/ Use	**Units**	**Household**	**Government**	**Industries**	**Fire-intolerant *Callitris* woodlands**	**Inland floodplain eucalypt forests and woodlands**	**Wetlands**	**Cultivated areas**	**Re-sprouter temperate and subtropical eucalypt woodlands**	**Lowland Streams**	**Fire-intolerant *Callitris* woodlands**	**Inland floodplain eucalypt forests and woodlands**	**Wetlands**	**Cultivated areas**	**Re-sprouter temperate and subtropical eucalypt woodlands**	**Lowland Streams**
2010																
Supply	$ AUD				-	-	-	-	-	-	-	-	-	-	-	-
Use	$ AUD			-												
2015																
Supply	$ AUD				-	-	-	-	-	-	-	-	-	-	-	-
Use	$ AUD			-												

Note: Monetary supply of use from water flow regulation services has not been analysed given no physical supply and use could be calculated. '–' = 0

6.9 Ecosystem services and First Nations Australians

The Gunbower and Koondrook-Perricoota forests and wetlands sustain a wide range of benefits for which members of the Barapa Barapa and Yorta Yorta language groups have acknowledged cultural obligations and access.

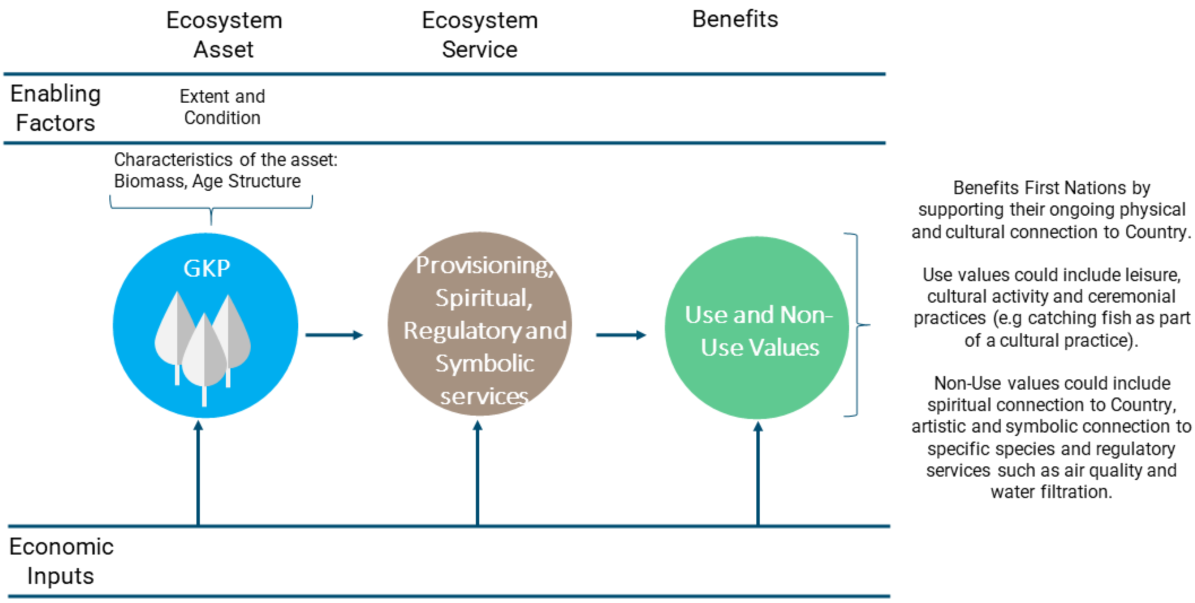
First Nations Australians cultural values, obligations and access are recognised in Commonwealth legislation (*Native Title Act 1993*; *Environment Protection and Biodiversity Conservation Act 1999*; National *Water Initiative 2004*; *Aboriginal Heritage Act 2006*; *Water Act 2007*), the Murray-Darling Basin Plan (2012), and early scholarly works commissioned by the MDB Commission such as Jackson et al. (2010). Cultural obligations to Country take place in everyday life, as Nation business under First Nations Australians governance systems, and within joint management partnerships with philanthropic and government agency programs (ARTD, 2017). The study site is no exception to such arrangements supported by the North Central CMA and the MDBA's The Living Murray Aboriginal Partnerships program. There is also the opportunity for First Nations Australians to be engaged in water management through the Murray Lower Darling River Indigenous Nations (MLDRIN) and Northern Basin Aboriginal Nation (NBAN) governance groups funded by the MDBA to advise on water policy.

Native title claims to the lands that contain the Gunbower and Koondrook-Perricoota forests and their waterways have been unsuccessful. The extent to which Nation business is addressing these issues is not discussed here. While maps with boundaries may not be constructive under these circumstances, such complexities should not exclude First Nations Australians from ongoing research into environmental accounting methods where the benefits have direct value to those language groups. First Nations Australians' claims, interests and perspectives are integral to methodological developments with potential for national application and interest, such as LEAP.

The extent to which the UN SEEA ecosystem accounts standard (2021) for cultural services meets First Nations Australians beneficiaries' expectations is a topic of ongoing investigation. Currently the ecosystem account standard includes 'Spiritual, artistic and symbolic services' as a subset of 'cultural services'. This standard reflects both use and non-use values but does not adequately reflect the use of other services such as regulatory and provisioning services.

In the SEEA EA framework, ecosystem services that can be linked to First Nations Australians will vary depending on the context but may include provisioning services (for example, fishing) and spiritual, artistic and symbolic services obtained through inherited cultural connection. The cultural connection between First Nations Australians and their land (known as "Country") is part of a living culture; the cultural services derived are diverse and extend beyond spiritual, artistic and symbolic services. They may overlap with provisioning services and have economic and commercial value. First Nations Australians also benefit from the various regulatory services provided by the ecosystem. The Echuca Declaration (MLDRN, 2008, NBAN, 2010) is a covenant operating in this category, defining "cultural flows" as a right to First Nations Australians water entitlements to support social, economic, cultural spiritual and environmental conditions. A subset of ecosystem services provided to First Nations Australians by GKP ecosystem is proposed in Figure 35.

Figure 35 Suggested supply of ecosystem services to First Nations groups in the study site.



While being a global organising framework, the UN SEEA is a stranger to most First Nations Australians, and yet its business is fundamentally their own – valuing the services that ecosystems generate to sustain life and culture. Within the Murray-Darling Basin several ecosystem assessment studies set baselines that included "cultural" services, but only two such studies included First Nations Australians in the work (Ngarrindjeri Nation and Birckhead et al. 2011; Ngemba Nation and Maclean et al. 2012). Other studies relevant to the case study sites and involving First Nations Australians include the Aboriginal Waterways Assessment work carried out by MLDRIN with Barapa Barapa (Mooney and Cullen 2019), DELWP's compilation of First Nations Australians' contributions to Victoria's water resource plans involving all three Nations relating to the study site (2019), the McConachie et al. (2020) participatory cultural mapping study of the Gunbower Forest with Barapa Barapa Nation representatives, the Pardoe and Hutton study (2021) also working with Barapa Barapa into the archaeology of a wetland village at Pollack Swamp in Koondrook-Perricoota Forest (2020). These studies do not relate to UN-SEEA but they provide information that makes First Nations Australians' preferred approaches to knowledge about ecosystems and their benefits visible.

Translating these preferences to the UN SEEA requires cross-cultural engagement to consider the consequences of use and cultural implications of the UN SEEA framework to Basin First Nations Australians. Work may follow on ecosystem benefits and their valuation, monetary and otherwise, as articulated by the First Nations Australians. This work has been discussed with Basin First Nations Australians and is in view for the Murray-Darling Water and Environmental Research Program (2021-25) with implications for the LEAP Commonwealth Partners and the CSIRO.

6.9.1 Cross-cultural protocols

Barapa Barapa have stressed that any engagement regarding Country needs to have Barapa Barapa people involved from the outset; Yorta Yorta exert the right to Free Prior Informed Consent when engaging within their Traditional lands (DELWP 2019). In some texts Wemba Wemba Nation is included as a Nation with cultural connection to the Gunbower study site, and multiple Nations are identified with interests in the Koondrook-Perricoota Forest in consideration of habitation prior to European arrivals (Harrington and Hale 2011).

Australian governments and research organisations are aware of standards of cross-cultural engagement to ensure First Nations Australians' self-determination. Such standards are:

- The United Nations Declaration of the Rights of Indigenous Peoples which refers to the principles of Free, Prior and Informed Consent (2007) endorsed by the United Nations Permanent Forum on Indigenous Issues (UNPFII) at its Fourth Session in 2005 to which Australia became a signatory in 2009.
- The Australian Institute for Aboriginal and Torres Strait Studies Code of Ethics (2020) which built on earlier work (1999) and which guides the formation of partnerships, design and planning of research projects in reference to Aboriginal knowledge systems.
- The Nagoya Protocol on Access and Benefit Sharing under the Convention on Biological Diversity includes recognition of the need to recognise traditional knowledge of genetic resources and make provisions of access and benefit sharing an element of Free, Prior ad Informed Consent.
- The CARE principles for Indigenous Data Governance which is an international standard complying with the United Nations Declaration of the Rights of Indigenous Peoples, relating to self-governance and authority to control inheritances and cultural assets as captured in data, data ownership, management and use. These principles are reflected in Productivity Commission's Australian Government's Indigenous Program Evaluation Strategy (2020).

Over and above the local and conceptual complexities discussed above, the limitations of project resourcing, competing demands on participant time, and the impacts of the global pandemic meant the above standards could not be followed for this current work. To ensure that First Nations Australians' voices are included in the LEAP case study reporting, a synthesis of published works that have complied with these standards is presented here.

6.9.2 Understandings

One Christmas we went out to the Gunbower Forest near Koondrook with five families… You could see shrimps and yabbies swimming in the shallow water. When you did go out you were sure to catch cod, silver bream or perch and red fin… Plant life that was used for medicinal purposes were plentiful too – like Old Man Weed. Also your reeds and Nadu plants… there were the river mussels and the tree grubs too. Tree grubs are a food source too. (Elder, Aboriginal Submissions Database, 2013, MDBA)

Barapa Barapa has developed an assets framework for their Country with substantial detail about the extent and condition of those assets (DELWP 2019). It is made up of the following distinctions:

- Plants
- Animals
- Water

- People
- Cultural heritage: tangible
- Cultural heritage: intangible
- Kulayatang (wet)
- Cultural plants
- Yumurrki (Dreaming)
- Yawir (fish)
- Tya (soil/land)
- Kunawar (Black Swan)

Taking this work and other studies into account, the concept as developed by Barapa Barapa is important for the LEAP to consider. It should also include Barapa Barapa Nation's cultural knowledge of and obligations for the regulatory, provisioning and cultural services of:

- Surface and ground water supply and quality
- Land and water food webs for provisioning
- People and all living things as part of ecosystems as cultural connection
- The importance and meanings of heritage, culturally significant places and species as cultural identity
- Spiritual appreciation within Country as a connected living system for culturally specific health and wellbeing.

Benefit sharing related to Barapa Barapa Country as stated in the framework and other works includes:

- Employment and economic participation in water-based businesses, trading and networks
- Cultural and social wellbeing, including physical health, artistic expression, habitation, freedom of movement, storytelling, and cultural education on Country
- Participation in cultural practices such as women's and men's business, protecting Country and knowledge, traditional harvesting and related ceremony, consumption and production, hunting, fishing and burning, and centrality to management decisions about Country (McConachie et al. 2020, Mendham and Curtis 2010 Pardoe and Hutton 2021)

Barapa Barapa Nation will not benefit from the ecosystem services that underpin their cultural knowledge systems, and fund their cultural economies, their social and individual wellbeing if water management does not include culturally distinguished environmental functions. Particular to First Nations Australians is legislative and regulatory reform which repositions their preferences in natural resource management and addresses the legacies of historic and forced removal from lands. Such work is ongoing but how it is to be accounted for is not resolved.

Yorta Yorta Nation have been included in published consultations and research about Country both with Barapa Barapa and other Nations, and with independent scholars including Yorta

Yorta scholars. The latter have been focussed on conceptual work related to ecosystem services and natural resource management, but not publicly applied to the specific characteristics of Yorta Yorta Country at the LEAP study site. The only observations that can be made from available material related to the study sites and to which Yorta Yorta Nation contributed, are:

- The Barapa Barapa assets framework cannot be assumed to apply to Yorta Yorta or any other Nation
- Adaptation to climate change is likely to have some synergies with Yorta Yorta customary law and practices as it will require longer time frames (Griggs et al. 2013 cited in Strong, Allen and Finlayson 2017; Lynch et al. 2012)

The North Central CMA's work on sustainable land management which included both Barapa Barapa and Yorta Yorta Nations amongst others, makes a comprehensive summarising statement:

> *There are many important places for Aboriginal people across north central Victoria. These areas are important for various reasons including obtaining sustenance, expressing themselves artistically, passing on creation stories and cultural values, engaging in conflict, establishing alliances and social networks, trading goods, celebrating rites of passage and committing the departed to their final resting places. Underpinning these material aspects of Aboriginal cultural heritage are intangible places where there may be no physical evidence of past cultural activities. These include places of spiritual or ceremonial significance, places where traditional plant or mineral resources occur, or trade and travel routes. Information about such places may be passed down from one generation to the next or may survive in nineteenth century documents and records. (NCCMA, 2013, p.144)*

6.9.3 Knowledge gaps

There are several knowledge gaps that need to be resolved for future work with First Nations Australians in the LEAP, including:

- How to engage with First Nations Australians on agreeing an approach that links the UN SEEA with national accounts and local First Nations Australians approaches to identifying, managing and sharing benefits from ecosystem services
- How to ensure First Nations Australians' rights to benefits are not overtaken by non-indigenous specific developments
- Other matters related to codifying, measuring and valuing benefits, including the use of such information for decision support will be addressed on the first two being resolved.

6.9.4 Areas for improvement

- Progress this work through the MD-WERP in partnership with MLDRIN and NBAN.
- Simultaneously plan for and fund dialogue with Nations relating to future ecosystem assessments within the LEAP from the earliest stages of such work.
- Link such developments to national scale First Nations groups such as the National Association of Community Controlled Health Organisations, and impacted Commonwealth agencies such as the National Indigenous Australians Agency and jurisdictional bodies who have already made significant strides in this work.

6.10 Recreation-related services

Recreational activities include people's experiences in the GKP environment. Recreation-related services are used by households and the characteristics and condition of the GKP ecosystem may impact the quantity of services that households demand.

Households can engage the tourism industry to participate in recreation activities in the GKP, or they can consume them directly (household consumption), for example, in the case of recreation-based fishing. There is thus an important link between the ecosystem, its condition, the species that inhabit it, and recreation services.

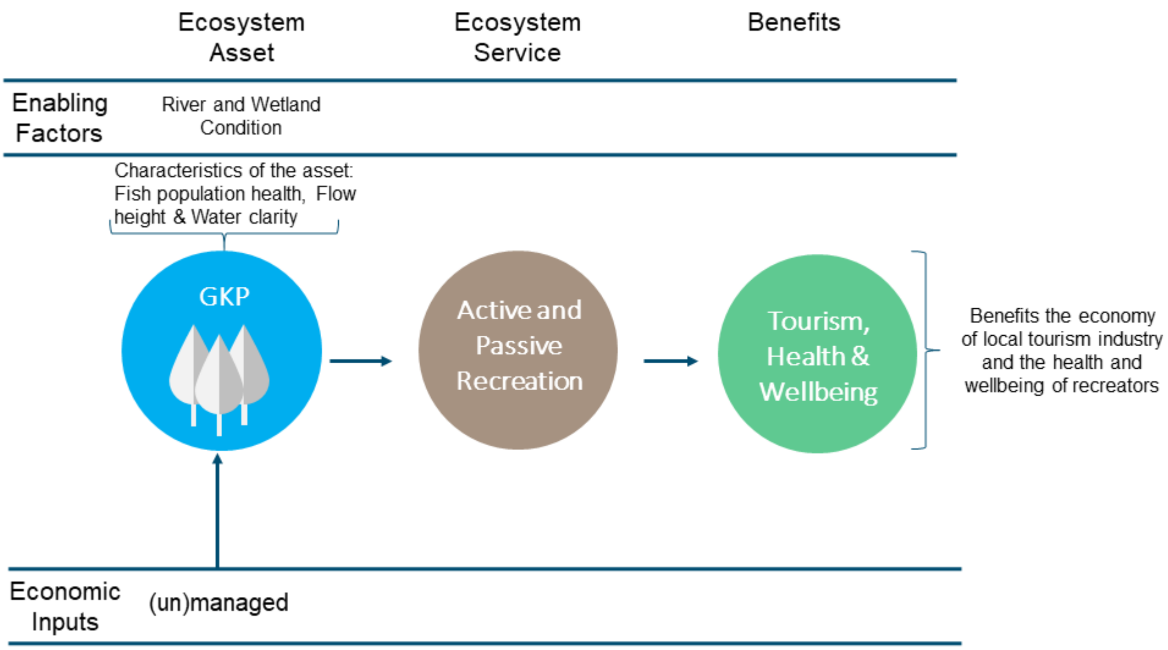
The main transaction of interest in this context is the relationship between the GKP ecosystem and recreation-related services. Figure 36 shows the relationship between the ecosystem service and people.

There are other relationships that are not captured explicitly in Figure 36 but are important to consider in recreation demand. For example, recreation demand will also be determined by factors such as the type and quality or accommodation, and services provided in towns surrounding GKP. For people undertaking multi-destination and multi-purpose trips, the location and proximity of these other destinations and purposes will also play a part in determining how often and how long people visit GKP.

The link between the ecosystem (quantity and quality) and the recreation activity (visitors and visit days) are key components of the narrative. The quantity and quality of GKP assets can affect the quantity of all recreation transactions now and into the future.

A complete information set will capture each recreational activity or transaction, estimate the potential value of the recreation transactions, and link them to one or more ecosystem assets to understand how the attributes and condition of the ecosystem affects the transaction. Government can contribute to the set of information outlined in Figure 36 to support the ongoing management of the GKP ecosystem.

Figure 36 Recreation-related services



6.10.1 Method

Physical and monetary ecosystem service accounts were produced in this analysis. A particular focus of the ecosystem service accounts was to integrate the account ready extent and condition data outlined in the previous chapters. A summary of the method for the physical supply and use is provided in Box 18 and a summary of the method for the monetary supply and use is provided in Box 19. Detailed methods for both ecosystem service accounts are outlined in the technical report (Cheesman et al. 2021). All datasets relied on for the analysis of ecosystem services are referenced at the bottom of the account tables.

Box 16 Approach to producing physical ecosystem service accounts

The number of visitor days to GKP can be used as a measure of recreation-related ecosystem service supply. The number of visitor days to Gunbower, KP and GKP in 2010 and 2015 have been estimated directly for the populations of Victoria, New South Wales (NSW), and South Australia (SA).

Using visitor days as the basis for supply and use provides a more accurate linkage between ecosystem supply and recreational use than visitor numbers.

- Domestic day visitor days and domestic overnight visitor days are estimated using results from a dedicated online survey conducted in March 2021. Respondents were drawn from a professional survey provider database, Pureprofile. The online survey included approximately 1,300 respondents from ACT and NSW, 1,100 from Victoria and 560 from SA. The online survey included approximately 1,300 respondents from ACT and NSW, 1,100 from Victoria and 560 from SA.
- Domestic visitor days are defined as visitors from ACT, NSW, Victoria and SA of any age who travel for a round trip distance of at least 40km, and are away from home for at least one hour, and do not spend a night away from home as part of their travel. Same day travel as part of overnight travel is excluded (AusTrade 2021).
- Overnight visitor days are defined as visitors from NSW, Victoria and SA of any age who undertake trips that involve a stay away from home of at least one night, but less than one year, at a place at least 40 km from home.
- The survey (1) asked respondents about household details, including residential postcode (2) showed respondents a map and provided background details about the GKP (3) asked respondents if they had ever visited GKP between 2010 and 2021.
- If respondents said they had visited GKP between 2010 and 2021, respondents were asked whether they visited (i) Gunbower National Park (NP) only; (ii) Koondrook-Perricoota State Forest (SF) only; or (iii) both Koondrook-Perricoota and Gunbower.
- Respondents then completed separate visitor surveys for the Gunbower NP and Koondrook-Perricoota SF depending on which sites they had visited. Respondents who had visited Gunbower and Koondrook-Perricoota completed both surveys.
- The visitation surveys asked respondents standard visitation questions needed to generate zonal travel demand models, and consistent with earlier evaluations (Stoeckl and Mules 2006; Gillespie et al. 2017; Dyack et al. 2007). These questions included obtaining information on group size, visit duration, activities during the visit, and accommodation type (if overnight).
- Respondents were also asked whether their visit was part of a multiple destination visit. Where the visit was part of a multi-destination visit, respondents were asked about the relative importance of the GKP visit based on (i) the number of days they visited GKP out of the total days visiting and (ii) using an importance weight (scored as 0% for no importance to 100% as the primary reason).

Survey results were used to estimate population weighted domestic day and overnight visitor numbers, and domestic day and overnight visitor numbers by reported recreation activities. Survey responses were reweighted using iterative proportional fitting, so they were representative of the NSW, Victorian and SA populations by location (metro versus regional for NSW, Victoria, and SA), age, gender, and income.

Recreational activities supply and use estimates are developed using visitor to population ratios for NSW, Victoria and SA. Estimates are based on the observed visitation rate from the weighted survey results, and the population of that zone, such that:

$$V_{y,i,z} = \frac{v_{y,i,z,d} + v_{y,i,z,o}}{n_z} * Pop_{y,z}$$

Where:

$V_{y,i,z,o,a}$ is the estimated number of visitor days in year (y), at geographic location (i) from travel zone (z)

$v_{y,i,z,d}$ is the survey weighted number of recreational visits reported by survey respondents in year (y), at geographic location (i) from travel zone (z), that are day trips (d).

$v_{y,i,z,o}$ is the survey weighted number of recreational visits reported by survey respondents in year (y), at geographic location (i) from travel zone (z), that are overnight (o)

n_z is the survey weighted number of total survey respondents for travel zone (z). This includes all respondents, those who said they had travelled to Gunbower and / or Koondrook-Perricoota during 2010-21 and those who said they had not.

$Pop_{y,z}$ is the resident population of travel zone (z) in year (y).

Travel zone (z) was separated by state (NSW, VIC, SA) and zonal distance measured as a straight line from Gunbower NP (<50kms, 51-250kms, 251-450kms, 451-650kms, 651-850kms, 851-1,050kms and 1,051kms+). Resident population in 2010 and 2015 by zone were extracted from ABS geopackages (AusTrade 2021) (Table 45).

Visitation estimates were compared with other recreation surveys of the Gunbower NP (E and Curtis 2018; Natural Capital Economics 2019). Local tour and park operators, to test what the survey results are suggesting in terms of visitation counts.

Note: The approach is explained in full in the accompanying technical report
Source: Cheesman et al. (2021)

Box 17 Approach to producing monetary ecosystem service accounts

The SEEA EA describes several approaches to monetary valuation that can be applied in the context of recreation-related services. One approach is the travel cost method (TCM), a technique that has been commonly used to estimate the value of recreational areas based on revealed preferences of visitors to sites. Commonly, TCM is used to derive a measure of the welfare value of the site, i.e. including the consumer surplus. The SEEA EA advises that exchange values may be approximated based on aggregated travel cost data or, where such data are unavailable, summing relevant consumption related expenditures at the site (SEEA EA 9.46-9.47).

In this GKP application we have used the consumption expenditure approach. This approach broadly aligns with and improves earlier work estimating recreation visitation at Gunbower (NCEconomics 2020) and other recreation demand studies evaluating demand for on- and near- water activities in Australia (Gillespie et al. 2017).

In the GKP application, consumption expenditure is interpreted as a proxy for the exchange value reflecting the amount people would be willing to pay additional to the actual consumer expenditure incurred. Under this interpretation we would assume that if the ecosystem did not exist, these expenses would not be made. Hence, the additional consumption expenditure is interpreted as the exchange value of the ecosystem contributions. Note here that using this approach the exchange value might be overstated given price elasticities of demand are ignored. Consumption expenditure on recreation at GKP is defined as:

$$\$\mathbf{RCE}_{y,i,z} = \left(\mathbf{2} * \boldsymbol{D}_{y,i,z} * \boldsymbol{TC}_{y}\right) + \left(\boldsymbol{v}_{y,i,z,d+o} * \boldsymbol{SC}_{y}\right)$$

Where:

$\$\mathbf{RCE}_{y,i,z}$ is the consumption expenditure cost for recreation in year (y), at geographic location (i) from travel zone (z).

2 accounts for the return trip.

$D_{y,i,z}$ is the distance in year (y) from geographic location (i) and the originating travel zone (z)

TC_y is the cost per km to travel to the site. This cost includes vehicle cost.

$v_{y,i,z,\boldsymbol{d+o}}$ is the estimated number of visitor days (d) and overnight visitor days (o) in year (y), at geographic location (i) from travel zone (z).

$\boldsymbol{SC}_y$ is the cost incurred while at the recreation site, including accommodation costs.

Recreators may visit GKP as part of a multi-destination and / or multi-purpose trip. In this case, trip costs need to be apportioned across destinations, otherwise consumption expenditure will be overstated for the GKP trip. Our approach to attributing values for multi-destination and multi-purpose trips follows (Dyack et al. 2007; Martinez-Espineira and Amoako-Tuffour 2009; Driml et al. 2020) by using an importance scale. This approach is subjective, but it considers that the importance of visits is unlikely to be simply a function of the time spent by the multi-destination visitor on each destination. For respondents who reported visiting Gunbower and Koondrook-Perricoota in the same trip, costs are apportioned based on time reported spent in each location.

The opportunity cost of time is calculated assuming direct travel time (i.e. the lowest opportunity cost of time). For adults, the opportunity cost of travel time was assumed to be 35% of the median annual wage for Statistical Subdivision the population comes from. For persons under 18 and over 65 years, the opportunity cost of travel time was taken at a quarter of that of adults. This approach is consistent with (Gillespie et al. 2017). Because the opportunity cost of time proved to be similar across SA, NSW and Victorian metro regions, and regional areas, time estimates were aggregated into a single metro opportunity cost estimate and a single regional opportunity cost estimate, based on respondents' residential location.

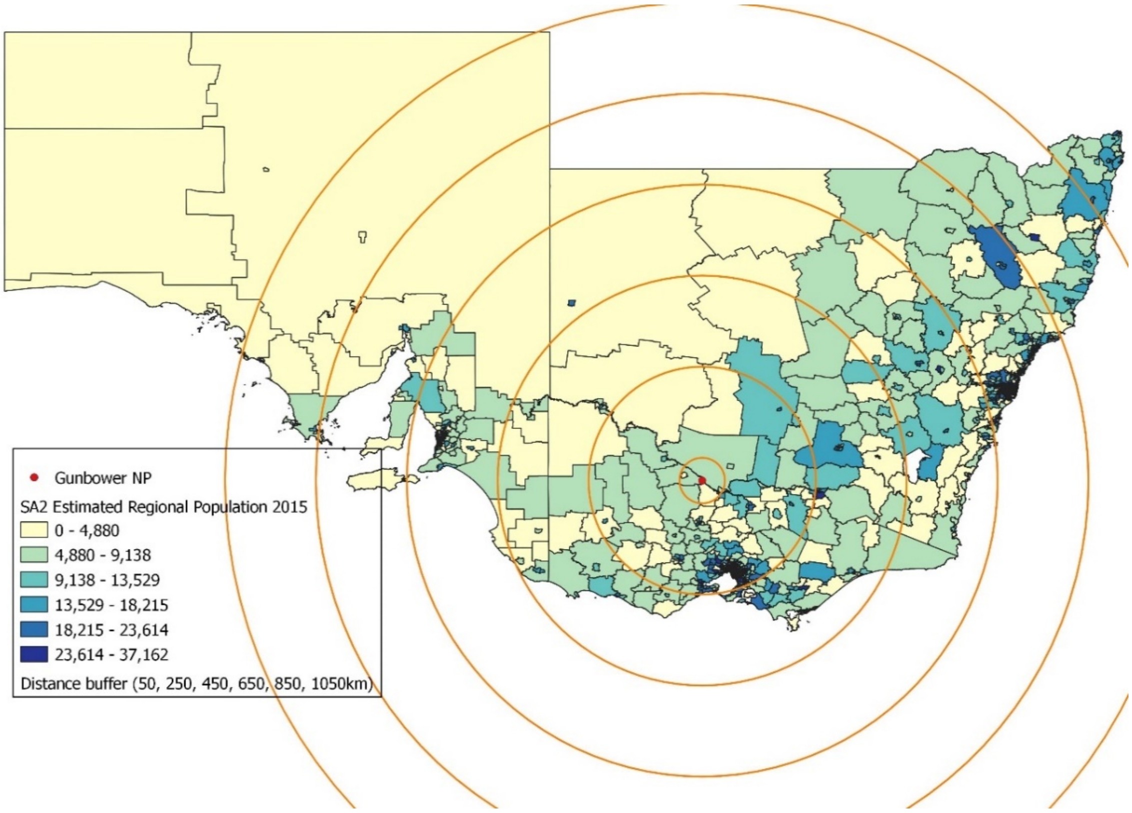
Consistent with the approach in (Gillespie et al. 2017; Heagney et al. 2019) we only include travel time to the site in opportunity costs. This makes our estimate of the opportunity cost of time relatively conservative.

Average vehicle cost per km are based on standard Australian Taxation Office rates – which are approximately $0.75 per km in 2010 and 2015. This figure includes vehicle depreciation and other costs in addition to fuel costs. An alternative approach would be to use fuel costs only, which would yield lower travel cost estimates, as in (Heagney et al. 2019). Average travel costs per trip per person are derived by sharing total vehicle costs pro-rata across the average number of persons reported travelling per trip per zone.

Day and overnight expenditure were based on survey data from a comprehensive survey of recreational expenditure by participants at 22 Recreational Water Facilities in Victoria in 2016-17 (Street Ryan 2017). We assume similar per visit day expenditures in 2010 and 2015 as in 2016-17. Overnight expenditures (for accommodation) are derived by sharing accommodation costs pro-rata across the average number of people per trip per zone. Assumed expenditure per person per day trip was set at $18, and $55 per person per overnight per overnight trip, with overnight trip costs reflecting that camping and staying with friends account for more than 70% of overnight stays.

Note: The approach is explained in full in the accompanying technical report
Source: Cheesman et al. (2021)

Table 45 ERP by zone, 2015



6.10.2 Areas for improvement

The approach applied to estimate recreation use and value improves on earlier approaches in several ways:

- supply and use accounts are based on recreation days from visitation. This is a more accurate estimate of actual consumption use than measuring visitor counts.
- The approach accounts for multi-purpose trips. Using an importance scale for multi-purpose trips provides a robust approach to attribute consumption expenditure to GKP versus other trip objectives.
- Including the opportunity cost of travel time consistent with approaches for including final consumption expenditure in national accounts and the payment of wages and salaries in kind.

The key areas for improvement relate to the recreation survey. For this evaluation, survey respondents were asked about visits to GKP in 2015 and 2010. This requires the ability to accurately recall trip details, which introduces the likelihood of recall error.

Survey results suggest recall error was an issue for Greater Sydney respondents. Survey results for the Greater Sydney population yielded much higher visitor and visitor day estimates than anticipated. Ground-truthing with local Councils, accommodation providers and other sources near GKP all suggest the Greater Sydney recreation estimates were significantly overstated, and that most visitors come from Greater Melbourne and Victoria, not Greater Sydney and NSW. This concords with evidence from earlier visitor surveys for Gunbower NP (E and Curtis 2018; Natural Capital Economics 2019).

To address the limitations with the Greater Sydney survey results we assume that the visitation incidence for Greater Sydney is approximately the same as the visitation incidence for Greater Melbourne population in 2010 and 2015. This assumption yields a more conservative estimate, and visitor and visit day estimates that concords more with evidence from earlier visitor surveys for Gunbower NP (E and Curtis 2018; Natural Capital Economics 2019). A travel cost model was not estimated in this evaluation, given the limitations of the Greater Sydney survey results, and the risk that a travel demand model using Greater Sydney recreation counts would be biased. See the technical report for more discussion (Cheesman et al. 2021).

Given the priority of GKP as an Icon site, recreation at GKP should be more comprehensively monitored in the future. This could involve undertaking systematic annual surveying, with travel cost method applications in mind. The survey developed for the current GKP evaluation could be used as the basis for these future survey evaluations. Respondents should be surveyed about their visits in the last 12 months to minimise recall error bias.

In Victoria, Parks Victoria completes biennial surveys and face-to-face interviews known as the Visitor Number Monitor (VNM) as part of their integrated research program. To develop a standard recreation and visitation survey approach in Victoria, DAWE, and Victorian CMAs partner with Parks Victoria to gather information through the VNM.

6.10.3 Accounting outputs

A recreation-related services physical supply and use table (Table 46) and monetary supply and use table (Table 47) was developed for the accounting area. Supply and use tables show the relationship between recreation supplied, the GKP ecosystem, and households as the user. This approach aligns with the SEEA framework.

The limitations with the Greater Sydney survey results should be kept in mind when interpreting the recreation accounting outputs.

In 2010, total visit days to Gunbower and KP are estimated at 211,000 (Table 46). Note this is total visit days, not visits. The ecosystem services technical report (Cheesman et al. 2021) includes total visits. Around three quarters of total visit days are in Gunbower NP. Average visitor days per visit are around 1.35 visitor days for Gunbower NP and around 1.2 visitor days for KP.

In 2015, total visit days to Gunbower and KP are estimated at 340,000 (Table 46). Note this is total visit days, not visits. The ecosystem services technical report (Cheesman et al. 2021) includes total visits. Around three quarters of total visit days are in Gunbower NP. Average visitor days per visit are around 1.55 visitor days for Gunbower NP and around 1.2 visitor days for KP.

Consumption expenditure in Table 47 includes drive and visit consumption expenditure totals and excludes opportunity costs. Consumption expenditure are based on visitation from Greater

Sydney being at the same incidence level as Greater Melbourne. This yields a more conservative estimate than using the Greater Sydney expenditure estimates, which are presented in tables in the ecosystem services technical report (Cheesman et al. 2021).

In 2010, consumption expenditure attributable to Gunbower and KP are estimated at $14.3 million (Table 47). Around three quarters of total consumption expenditure is attributable to Gunbower NP.

In 2015, consumption expenditure attributable to Gunbower and KP are estimated at $21.7 million (Table 47). Around 72% of total consumption expenditure is again attributable to Gunbower NP. The welfare value of recreation was also calculated for comparison with the exchange-based figures in Table 47. The welfare value is not a direct exchange and, as a result, sits separate from the ecosystem physical and monetary supply and use tables. The welfare value is presented here to demonstrate the potential gap between the value the market currently places on recreation and the benefits available from recreation for society.

Using mid-range estimate data from Table 64 and 65 in the Technical Report (Cheesman et al.2021), and applying the same assumption that informed the physical and (exchange-based) monetary flows (i.e. Greater Sydney = Greater Melbourne), the monetary supply and use of welfare-based values (using consumer surplus) increases from $19.3M in 2010 to $31.3M in 2015.

Table 46 Recreation-related services, physical supply and use table, GKP, 2010 and 2015

Supply /Use	Units	Economic units			Ecosystem type													
					Gunbower							Koondrook-Perricoota						
		Household	Government	Industries	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams	Total	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams	Total
2010																		
Supply	Visit days				-	-	-	-	-	-	156,000	-	-	-	-	-	-	55,000
Use	Visit days	211,000		-														
2015																		
Supply	Visit days				-	-	-	-	-	-	252,000	-	-	-	-	-	-	88,000
Use	Visit days	340,000		-														

Note: '–' = 0, Confidence in data is moderate.

Table 47 Recreation-related services, monetary supply and use summary table, GKP, 2010 and 2015

Supply/Use	Units	Economic units			Ecosystem type													
					Gunbower							Koondrook-Perricoota						
		Household	Government	Industries	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt	Lowland Streams	Total	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt	Lowland Streams	Total
2010																		
Supply	$AUD				–	–	–	–	–	–	10,556,000	–	–	–	–	–	–	3,756,000
Use	$AUD	14,312,000	–	–														
2015																		
Supply	$AUD				–	–	–	–	–	–	15,700,000	–	–	–	–	–	–	6,028,000
Use	$AUD	21,728,000	–	–														

Note: '–' = 0, Confidence in estimates is moderate.

7 Ecosystem asset valuation

7.1 Introduction

The ecosystem asset valuation involves estimating the monetary value of the opening and closing stocks of all ecosystem assets within the GKP ecosystem accounting area and the value of additions and reductions in those stocks (UNCEEA 2021). Estimates of the monetary value of ecosystem services were compiled using the exchange value concepts described in the Ecosystem services accounting chapter. In the ecosystem asset accounts a separation is made between 'use values' (Table 48 to Table 50) and 'non-use values' (Table 51 to Table 53). The 'use value' based ecosystem asset valuations within this chapter facilitate integration with the values of other assets such as buildings, machinery and equipment, and financial assets.

In most cases, monetary values of ecosystem assets are estimated based on the net present value (NPV) of the expected future flows of all ecosystem services generated by an ecosystem asset. This requires an understanding of the likely pattern for the supply and use of each ecosystem service and recognition that the pattern of supply among different ecosystem services from a single ecosystem asset is likely to be correlated. A key aspect in understanding the pattern of future flows of ecosystem services is the connection to the condition of the ecosystem asset. The connection between services and condition is reflected in the concept of ecosystem capacity. The measurement of ecosystem capacity also links to the measurement of ecosystem degradation, i.e. the decline in the condition of ecosystem assets as a result of economic and other human activity. The estimation of NPV also requires the selection of a discount rate and this choice can have an important impact on the resulting valuations. Further testing and research is required in many areas related to measuring the monetary value and capacity of ecosystem assets including the application of NPV techniques for ecosystem assets, estimating future patterns of ecosystem service flows, the measurement of ecosystem capacity and the valuation and attribution of ecosystem degradation.

Entries in the monetary ecosystem asset account go beyond the measurement requirements of the ecosystem services flow account in monetary terms by incorporating the use of NPV techniques and assumptions about the flow of services in the future. It is assumed that the flows of individual services are mutually exclusive and that their values can be aggregated.

There are other relationships that are not captured explicitly within this analysis but are important to consider in ecosystem asset valuation. The future flow of services provided by the GKP ecosystem relies on both the current and future condition of the ecosystem (including the natural regeneration of the ecosystem) and future uses of ecosystem services. For example, the value of an ecosystem asset in relation to its ability to enable timber harvesting depends upon (i) the standing stock of timber at a given moment; (ii) the expected (re)growth of the timber stock, which, in turn, is a function of ecosystem condition indicators such as soil fertility; and (iii) expected demand for timber products.

Socio-economic variables are also key in determining the quantity and value of future flows. Population growth, patterns of recreational use and future values of ecosystem services (for example, the exchange value of carbon sequestration) could all change in the future. These factors were not modelled in this analysis and are all important to consider for future works.

Assuming that the NPV for each type of service is separable, it is possible to consider the total value and changes in value for each ecosystem service flow separately. This assumption may be considered significant in light of the complexities and linkages in the supply of ecosystem services. From an accounting standpoint, the effect of this assumption will depend on the extent to which the factors affecting the future supply of services and the associated asset lives that underpin the NVP calculations are considered in an integrated and coherent manner. If these variables are estimated for each service independently, then it is likely that the separability assumption will be problematic. However, if the potential linkages between services are considered then the concern should be reduced.

The links between each service supplied by the GKP ecosystems, and the influence that the provision of one service has on another, are key components of the wholistic ecosystem narrative. For example, if estimates of carbon sequestration services are made assuming that the GKP forests can sequester carbon over an infinite timeframe, while estimated rates of timber provisioning are made assuming the GKP forest is depleted within a limited time frame with no regeneration (for example, 30 years), then the two estimates of expected service flows should be considered internally inconsistent. In many cases, it is likely that asset lives for provisioning services involving harvest or extraction will provide an upper bound to the asset lives and should therefore be applied in estimation of all expected ecosystem service flows.

SEEA guidelines for ecosystem asset valuation is an evolving field and the method used in this analysis has a number of limitations that we discuss in the areas for improvement section below. A complete information set will capture the connections among all services and the pressures they exert on the provision of the others. It will also include a comprehensive analysis of the ecosystem capacity to continue providing all services in perpetuity. Government can contribute to the set of information outlined above to support the ongoing management of the GKP ecosystem.

7.2 Method

Monetary ecosystem asset accounts were produced for the GKP under the assumption of constant future flows and values of ecosystem services. The monetary ecosystem asset accounts rely on the valuation calculations for each service presented in Chapter 6. A summary of the method for the monetary ecosystem asset is provided in Box 20 below. Detailed methods for the ecosystem service accounts are outlined in the technical report (Cheesman et al. 2021). All datasets relied on for the analysis of ecosystem services are referenced at the bottom of the account tables.

Box 18 Approach to producing monetary ecosystem asset accounts

In ecosystem accounting, an ecosystem asset generates a bundle of ecosystem services each valued separately. The NPV formula is applied at the level of individual ecosystem services and the resulting discounted values are aggregated to derive the monetary value of the ecosystem asset. Note that where the ecosystem service values are based on observed market prices for associated benefits (for example, in the resource rent method), the costs incurred in supplying the ecosystem services will be excluded such that the value used considers only the contribution of the ecosystem.

In mathematical terms, the value of a single ecosystem asset V is written as:

$$V_\tau(\boldsymbol{EA}) = \sum_{i=1}^{i=S} \sum_{j=\tau}^{j=N} \frac{ES_\tau^{ij}(\boldsymbol{EA}_\tau)}{(1 + r_j)^{(j+1-\tau)}}$$

Where:

ES_τ^{ij} is the value of ecosystem service *i* in year *j* as expected in base year τ generated by a specific ecosystem asset $\boldsymbol{EA}_\tau$;

S is the total number of ecosystem services; *r* is the discount rate (in year *j*), *N* is the lifetime of the asset and τ is the starting period or base year, which may be referenced to 0.

The selection of discount rates is a longstanding challenge in asset valuation. The Office of Best Practice Regulation (OBRP) recommends 7% discount rates for current infrastructure projects but more recent research by the Grattan institute (Deans 2018) has recommended it be lowered in the face of current low interest rates. The Grattan institute recommends discount rates of 3.5% - 5% can be used for low-high risk infrastructure projects. This analysis presents results under a 2.5% discount rate with sensitivity analysis using discount rates of 4% and 7%.

The asset life may be infinite for some ecosystem assets if used sustainably. For this analysis, the lifetime of the assets and teir ecosystem service flows are assumed to extend into perpetuity.

τ is the starting period or base year, which may be referenced to 0.

Preferably, the returns should be assumed to accrue to the midpoint of the accounting period. The assumption made here is that the returns accrue at the start of the accounting period and hence the first period's flows are not discounted. This assumption is used to simplify the explanation and the associated notation but has no impact on the underlying relationships described.

A general description of how the monetary ecosystem asset accounts under constant assumptions for GKP were produced is outlined below:

- The provision of ecosystem services by each GKP ecosystem type was calculated. This is summarised in Chapter6: Ecosystem services accounting.
- The NPV of each individual ecosystem service was calculated in perpetuity for both 2010 and 2015. In 2010, the exchange value and yield observed in 2010 was assumed to remain constant into perpetuity. In 2015, the exchange value and yield observed in 2015 was assumed to continue into perpetuity.
- Assuming the exchange value remains constant means, for example, that the exchange value of carbon sequestration and the residual rents from biomass for timber in 2015 remain constant into the future. Further analysis could make broad assumptions of how these exchange values will change into the future.
- Assuming yield remains constant means, for example, that the quantity of biomass for timber and carbon sequestration supplied by each GKP ecosystem type in 2015, was assumed to continue into perpetuity. This is a key area of the method that can be focused on to improve the analysis and is discussed further in the areas for improvement section below. Assuming that the GKP ecosystems can continue to supply biomass for timber at the 2015 rate, and also provide the same quantity of carbon sequestration as provided in 2015 is likely a contradictory assumption. As a result, it is likely that the yields are overestimated under constant assumptions. Further research should be completed on the capacity of the GKP ecosystem to continue providing services into the future.

Note: The approach is explained in full in the accompanying technical report

Source: Cheesman et al. (2021)

7.3 Areas for improvement

A number of assumptions have been made when calculating the ecosystem asset valuation for GKP. Key assumptions are that ecosystem asset continues in perpetuity and physical supply of ecosystem services from assets is constant. Physical supply is set constant at 2010 (opening value) and 2015 (closing value) for analysis of the present value into perpetuity and the discount rate is assumed to be 2.5%. Ideally, valuations would take into account a wider range of future environmental, political and social factors that will influence ecosystem supply and exchange values.

Additional research could focus on completing a detailed analysis of the GKP ecosystem's capacity to provide services into the future. Ecosystem services such as biomass for timber and biomass for firewood will have ecological limitations to their sustainable supply. Further, the impact that the supply of biomass for timber and firewood has on the rest of the ecosystem services, especially supply of carbon sequestration and stock, recreation and water flow should be analysed. The likely interdependence of services almost certainly extends beyond just timber provision and carbon sequestration services. Over time, recreation and other cultural ecosystem services are also likely to be impacted by the provision of timber biomass for example. Valuing these connected future benefits is a substantial and vital area for improvement of this analysis in the future.

Environmental factors will also impact the GKP ecosystems ability to provide ecosystem services. The future impact of climate change on the forest's condition and extent at current levels and into the future, which will culminate in increased periods of droughts, increased number of extreme weather events, increased likelihood of bushfires as well as the negative impact of rising temperatures themselves, should be analysed. This could take the form of a scenario analysis under different long-term forecasts of climate in the region.

It is important to note that the current analysis does not reflect the value of water flow regulation provided by the GKP ecosystem as no significant flooding events occurred in the study years. It is however likely that there will be floods in some years into the future and as a result assuming that the value of flood regulation remains at zero in perpetuity is unreasonable. This analysis has not been included in the accounts because of data limitations. Future modelling could include this application.

Similarly, the value of honey supported by GKP provisioning services is assumed to remain at zero in perpetuity as there were no significant flowering events in the key years. This ignores the ability of the GKP to provide flowering events in the future. Analysis of potential future honey production has not been included in the accounts as a result of data limitations. Future modelling could include this application, but we note that current trajectories of drying in the GKP mean flowering events are on the decline.

Finally, the values of all ecosystem services provided by the GKP but which are out of scope of this work have been omitted from the analysis. These services include, but are not limited to, local firewood collection, air quality filtration, water quality regulation, soil retention and soil quality regulation. In addition, there are expected to be significant non-use values associated with GKP, for example associated with its support for the ongoing existence of species. Only some of these non-use values have been identified in this work and future work should seek to address non-use values more comprehensively to gain a more complete understanding of the ecosystem asset valuation of the GKP.

7.4 Accounting outputs

Monetary ecosystem asset accounts were developed for use (Table 48 to Table 50) and non-use (Table 51 to Table 53) values within the accounting area. Ecosystem asset valuation tables record the monetary value of the opening and closing stocks of the relevant ecosystem assets within the GKP ecosystem accounting area and additions and reductions in those stocks.

Table 48 displays the monetary ecosystem asset accounts for use-values in the GKP ecosystem. The ecosystem services included in this assessment are biomass for timber, biomass for firewood, carbon sequestration and recreation. The ecosystem asset accounts are based on the exchange values of the respective services. As discussed in Section 6.5.1, the World Bank Median exchange value is preferred for carbon valuation in this analysis as these values reflect prices for carbon based on observed market transactions. The World Bank Median exchange value has therefore been applied in calculation of the ecosystem asset accounts. Policy analysis in the future can construct the ecosystem asset accounts with the ACCU's exchange value by applying it at a constant ratio. The flow of carbon sequestration services and ACCU exchange value remain constant into perpetuity. No welfare values are included in the estimates for asset accounts.

Physical supply and resource rents for each ecosystem service are assumed to remain constant at 2010 (opening value) and 2015 (closing value) levels into perpetuity. The closing balance of the monetary ecosystem asset account of GKP is around $4,673 million under assumptions of a 2.5% discount rate (Table 48). Additions to stock are recorded across most ecosystem types, Inland floodplain eucalypt forests and wetlands add around $448 million (NPV) in the Gunbower forest and $477 million (NPV) in the Koondrook-Perricoota Forrest. These additions are largely driven by the increase in value of carbon sequestration and recreation related services between 2010 and 2015. The Inland floodplain eucalypt forests and wetlands ecosystem asset stock is reduced by around $4 million (NPV) in Gunbower and $27 million (NPV) in Koondrook-Perricoota Forest within the assessment period. This is driven by the reduction in the biomass for firewood and timber supply observed between 2010 and 2015.

Table 49 and Table 50 represent a sensitivity analysis of the monetary ecosystem asset account for GKP and rely on discount rates of 4% and 7% respectively. Under an assumption of 4% discount rate the closing value is around $2,920 million (NPV). Under an assumption of 7% discount rate the closing value is around $1,669 million (NPV).

Table 51 presents the monetary ecosystem asset account of non-use values within the GKP ecosystem. This relies solely on the ecosystem and species appreciation exchange values and is calculated under a 2.5% discount rate. The opening value is $6,019 million (NPV) and the closing value is $4,513 milliion (NPV), this reduction is largely driven by lower exchange values per habitable hectare in 2015 compared to 2010.

Table 52 and Table 53 represent a sensitivity analysis of the monetary ecosystem asset account of non-use values within GKP and rely on discount rates of 4% and 7% respectively. Under an assumption of 4% discount rate the closing value is around $2,821 million (NPV). Under an assumption of 7% discount rate the closing value is around $1,612 million (NPV).

Table 48 Monetary ecosystem asset account – Use Values (2.5% discount rate)

		Ecosystem type												
		Gunbower				Koondrook - Perricoota					Total			
Asset value	**Unit**	**Fire-intolerant *Callitris* woodlands**	**Inland floodplain eucalypt forests and woodlands**	**Wetlands**	**Cultivated areas**	**Re-sprouter temperate and subtropical eucalypt woodlands**	**Lowland Streams**	**Fire-intolerant *Callitris* woodlands**	**Inland floodplain eucalypt forests and woodlands**	**Wetlands**	**Cultivated areas**	**Re-sprouter temperate and subtropical eucalypt woodlands**	**Lowland Streams**	**Total**
Opening value	$ AUD	72	1,083	72	70	119	70	47	1,797	35	25	73	25	3,488
Additions	$ AUD	35	448	35	34	54	34	21	477	18	15	28	15	1,216
Reductions	$ AUD	–	4	–	–	–	–	–	27	–	–	–	–	31
Net change in value	$ AUD	35	445	35	34	54	34	21	450	18	15	28	15	1,185
Closing value	$ AUD	107	1,527	107	105	173	105	68	2,247	53	40	101	40	4,673

Note: Monetary ecosystem asset accounts are estimated for 2010 (opening value) and 2015 (closing value), presented in NPV terms ($AUD millions). NPV calculations are forecast in perpetuity at 2.5% discount rate. This is one representation of the future monetary ecosystem assets and is a simplified analysis of the GKP ecosystem. Estimates can be improved with finer scale modelling of assumptions and more detailed analysis of the future of individual sectors. '–' = 0
Source: Input data from Ecosystem services accounting Chapter.

Table 49 Monetary ecosystem asset account – Use Values (4% discount rate)

		Ecosystem type												
		Gunbower						Koondrook-Perricoota						Total
Asset value	Unit	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams	Total
Opening value	$AUD	45	677	45	44	74	44	29	1,123	22	16	45	16	2,180
Additions	$AUD	22	280	22	21	34	21	13	298	11	9	18	9	760
Reductions	$AUD	–	2	–	–	–	–	–	17	–	–	–	–	19
Net change in value	$AUD	22	278	22	21	34	21	13	281	11	9	18	9	741
Closing value	$AUD	67	955	67	65	108	65	43	1,404	33	25	63	25	2,920

Note: Monetary ecosystem asset accounts are estimated for 2010 (opening value) and 2015 (closing value), presented in NPV terms ($AUD millions). NPV calculations are forecast in perpetuity at 4% discount rate. This is one representation of the future monetary ecosystem assets and is a simplified analysis of the GKP ecosystem. Estimates can be improved with finer scale modelling of assumptions and more detailed analysis of the future of individual sectors. '–' = 0
Source: Input data from Ecosystem services accounting Chapter.

Table 50 Monetary ecosystem asset account – Use Values (7% discount rate)

		Ecosystem type												
		Gunbower						Koondrook-Perricoota						Total
Asset value	Unit	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams	Total
Opening value	$AUD	26	387	26	25	42	25	17	642	13	9	26	9	1,246
Additions	$AUD	13	160	12	12	19	12	8	170	6	5	10	5	434
Reductions	$AUD	–	1	–	–	–	–	–	10	–	–	–	–	11
Net change in value	$AUD	13	159	12	12	19	12	8	161	6	5	10	5	423
Closing value	$AUD	38	545	38	37	62	37	24	802	19	14	36	14	1,669

Note: Monetary ecosystem asset accounts are estimated for 2010 (opening value) and 2015 (closing value), presented in NPV terms ($AUD millions). NPV calculations are forecast in perpetuity at 7% discount rate. This is one representation of the future monetary ecosystem assets and is a simplified analysis of the GKP ecosystem. Estimates can be improved with finer scale modelling of assumptions and more detailed analysis of the future of individual sectors. '–' = 0
Source: Input data from Ecosystem services accounting Chapter.

Table 51 Monetary ecosystem asset account – Non-use values (2.5% discount rate)

		Ecosystem type												
		Gunbower						Koondrook-Perricoota						Total
Asset value	Unit	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams	Total
Opening value	$AUD	4	1,818	44	31	88	54	48	3,174	598	3	109	48	6,019
Additions	$AUD	–	–	–	–	–	–	–	–	–	–	–	–	–
Reductions	$AUD	1	580	14	10	28	17	10	683	129	1	23	10	1,506
Net change in value	$AUD	-1	-580	-14	-10	-28	-17	-10	-683	-129	-1	-23	-10	-1,506
Closing value	$AUD	2	1,238	30	21	60	37	38	2,491	470	3	85	38	4,513

Note: Monetary ecosystem asset accounts are estimated for 2010 (opening value) and 2015 (closing value), presented in NPV terms ($AUD millions). NPV calculations are forecast in perpetuity. This is one representation of the future monetary ecosystem assets and is a simplified analysis of the GKP ecosystem. Estimates can be improved with finer scale modelling of assumptions and more detailed analysis of the future of individual sectors. '–' = 0
Source: Input data from Ecosystem services accounting Chapter.

Table 52 Monetary ecosystem asset account – Non-use values (4% discount rate)

		Ecosystem type												
		Gunbower						Koondrook-Perricoota						Total
Asset value	Unit	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams	Total
Opening value	$AUD	2	1,136	27	20	55	34	30	1,984	374	2	68	30	3,762
Additions	$AUD	–	–	–	–	–	–	–	–	–	–	–	–	–
Reductions	$AUD	1	362	9	6	17	11	6	427	80	0	15	6	941
Net change in value	$AUD	-1	-362	-9	-6	-17	-11	-6	-427	-80	-0	-15	-6	-941
Closing value	$AUD	2	774	19	13	37	23	24	1,557	294	2	53	24	2,821

Note: Monetary ecosystem asset accounts are estimated for 2010 (opening value) and 2015 (closing value), presented in NPV terms ($AUD millions). NPV calculations are forecast in perpetuity. This is one representation of the future monetary ecosystem assets and is a simplified analysis of the GKP ecosystem. Estimates can be improved with finer scale modelling of assumptions and more detailed analysis of the future of individual sectors. '–' = 0
Source: Input data from Ecosystem services accounting Chapter.

Table 53 Monetary ecosystem asset account – Non-use values (7% discount rate)

		Ecosystem type												
		Gunbower						Koondrook-Perricoota						Total
Asset value	Unit	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams	Fire-intolerant *Callitris* woodlands	Inland floodplain eucalypt forests and woodlands	Wetlands	Cultivated areas	Re-sprouter temperate and subtropical eucalypt woodlands	Lowland Streams	Total
Opening value	$AUD	1	649	16	11	31	19	17	1,133	214	1	39	17	2,150
Additions	$AUD	–	–	–	–	–	–	–	–	–	–	–	–	–
Reductions	$AUD	0	207	5	4	10	6	4	244	46	0	8	4	538
Net change in value	$AUD	-0	-207	-5	-4	-10	-6	-4	-244	-46	-0	-8	-4	-538
Closing value	$AUD	1	442	11	8	21	13	13	890	168	1	31	14	1,612

Note: Monetary ecosystem asset accounts are estimated for 2010 (opening value) and 2015 (closing value), presented in NPV terms ($AUD millions). NPV calculations are forecast in perpetuity. This is one representation of the future monetary ecosystem assets and is a simplified analysis of the GKP ecosystem. Estimates can be improved with finer scale modelling of assumptions and more detailed analysis of the future of individual sectors. '–' = 0
Source: Input data from Ecosystem services accounting Chapter.

8 Accounting for biodiversity

8.1 Introduction

Biodiversity refers to '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).

A wide array of data on ecosystems, species and genes support the measurement and assessment of biodiversity. The spatial focus of a biodiversity assessment may be regional, national or global in scale, and it may consider individual species, groups of species or ecosystems. Existing initiatives in biodiversity assessment can be harnessed to source data, indicators and approaches, ensuring coherence and consistency between environmental-economic accounts and for example, the post-2020 Global Biodiversity Framework.

The purpose in accounting for biodiversity includes informing conservation and enhancement of biodiversity as an environmental management objective in its own right, as well as supporting the understanding of how elements of biodiversity underpin flows of ecosystem services and benefits to people.

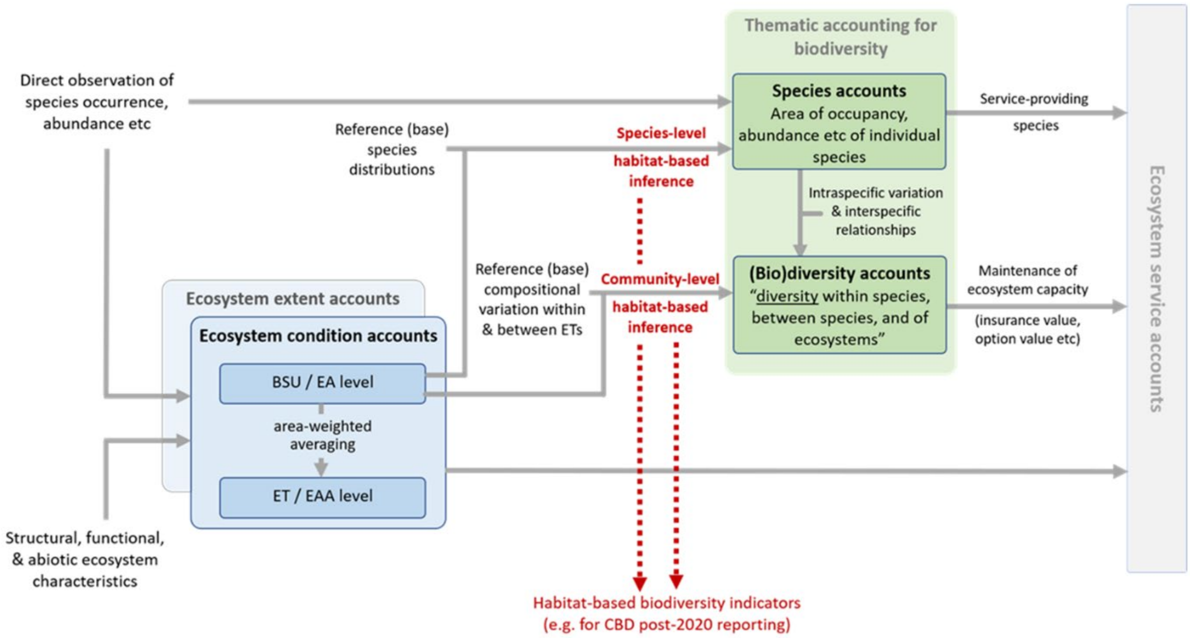
Biodiversity is relevant across all areas of the core ecosystem accounting framework including ecosystem extent, ecosystem condition, ecosystem services and benefits (Figure 37). Direct field-based data on biodiversity can support the compilation of ecosystem condition accounts and may provide input to the measurement of ecosystem services. Further, the information on ecosystem extent and condition can be used to support a basic understanding of the status and trends in biodiversity, across large spatial extents, through the derivation of habitat-based biodiversity indicators. As for all ecosystem accounting, biodiversity data needs to be coherent across the various ecosystem accounts.

Biodiversity was embedded in some (but not all) elements of the accounting framework in this project. The biodiversity assessment data is coherent with the data and concepts applied in the land accounts for all of Australia and the assessment of the extent and condition of ecosystems for GKP. Species-level biodiversity assessment data was used in the measurement of ecosystem and species appreciation but community-level biodiversity assessment data was not.

Accounting for biodiversity is not currently covered by an international statistical standard, but some guidance is provided in UNCEEA (2021) (including an example of species accounts in Table 13.2). The approach taken here aligns strongly with that guidance and the planned extensions.

The approach to biodiversity measurement used here assesses community-level and species-level data, using internationally accepted habitat-based approaches (Ferrier et al. 2017; King et al. 2017) and presents these data using accounting principles and guidelines to support decision-making.

Figure 37 Linkages between thematic accounts for biodiversity and ecosystem extent and condition accounts



Source: Larson et al. (2021)

8.2 Method

The biodiversity sub-project developed biodiversity data which was used to compile biodiversity accounts (Mokany et al. 2021a, 2021b). A summary of the approach is provided in Box 19. A number of additional datasets were used in the process of building the accounts and tables which have been referenced at the bottom of the accounting tables.

Box 19 Approach to producing biodiversity data

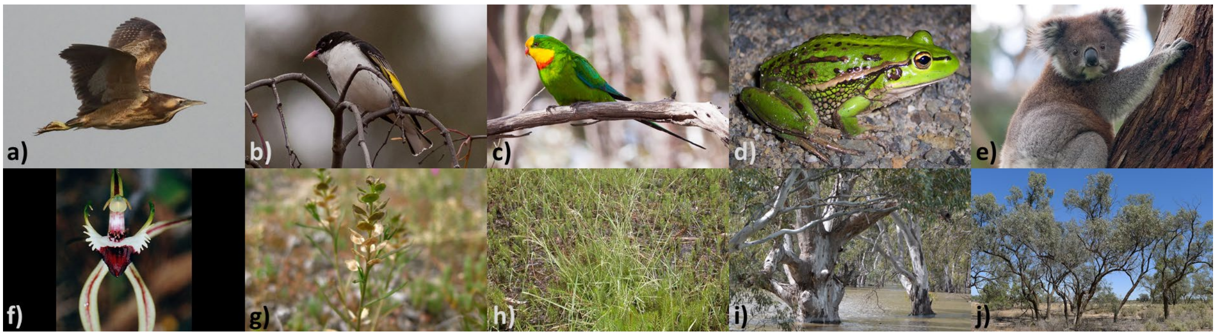
- Biodiversity data produced during this project can be separated into community-level and species-level biodiversity. Community-level measures of biodiversity are compiled for for vascular plants and waterbirds while species-level data are compiled for 10 focal species. In all cases a habitat-based approach was used to measure biodiversity.
- Expected species persistence – the percentage of species expected to persist over the long term within the ecosystem accounting area – is used as an indicator of community-level biodiversity for vascular plants. The approach for vascular plant assessment combines expected patterns in the distribution of biodiversity from spatial biodiversity models with a time series of spatially complete habitat condition data, derived from remote sensing data (King et al. 2016; Ferrier et al. 2017). Human land-use actions over time influence habitat condition for communities and species, which then influences expected biodiversity persistence into the future. This habitat-based approach can incorporate significant amounts of on-ground ecological survey data in deriving the spatial biodiversity models, ensuring that the estimated patterns of biodiversity closely reflect those observed.
- Waterbird species richness is used as an indicator of community-level biodiversity. The indicator was derived from 229,162 on-ground observations and modelled as a function of Water Observations from Space (WOfS) (Mueller et al. 2016) and a range of additional static environmental predictors.

The waterbird species richness model was then projected for 2010 and 2015, based on the WOfS data for those years.

- Suitable habitat within the potential extent of occurrence is used as an indicator of species-level biodiversity. For the species-level biodiversity assessment, a habitat-based approach was used, which aligns with the community-level methods and the broad habitat-based conceptual approach. This approach combines remote sensing with best-available mapping of the original (or 'reference') spatial distributions of the focal species (Barrows et al. 2008; Soberón and Peterson 2009; Tracewski et al. 2016; King et al. 2016; Brooks et al. 2019). Species-level accounts were developed for 10 focal species representing different taxonomic groups and threat status across both GKP and the Murray-Darling Basin (Figure 38).

Note: The approach is explained in full in the accompanying technical report
Source: Mokany et al. (2021a)

Figure 38 The 10 focal species



Note: a) Australasian bittern, b) painted honeyeater, c) superb parrot, d) growling grass frog, e) koala, f) rigid spider-orchid, g) winged pepper-cress, h) river swamp wallaby-grass, i) river red gum, j) black box.
Photo credits: a) Wayne Butterworth, CC BY 2.0, via Wikimedia Commons; b) and c) Ron Knight from Seaford, East Sussex, United Kingdom, CC BY 2.0, via Wikimedia Commons; d) Tnarg 12345 at the English-language Wikipedia, CC BY-SA 3.0, via Wikimedia Commons; e) Diliff, CC BY-SA 3.0, via Wikimedia Commons; f) Chris Lindorff, CC BY 2.5, via Wikimedia Commons; g) Chris Lindorff, CC BY 2.5, via Wikimedia Commons; h) Walsh, Neville, © 2021 Royal Botanic Gardens Board, CC BY-NC-SA 4.0; i) Margaret R Donald, CC BY-SA 4.0, via Wikimedia Commons; j) John Tann from Sydney, Australia, CC BY 2.0, via Wikimedia Commons.

8.3 Areas for improvement

In the biodiversity sub-project, the community-level biodiversity assessment for vascular plants used the most sophisticated techniques, which considered both landscape context as well as the full implications of habitat change for long-term persistence. Future work could apply these same techniques to waterbirds or other communities, or to species.

Future research could attribute the benefits for waterbird diversity of past or future environmental watering actions, through linking observed surface water coverage with that predicted using hydrological models under past or future scenarios. More broadly, different land use and climate change scenarios could also be used to predict impacts of future changes on biodiversity. This application is potentially useful for a range of decision making.

The 10 focal species considered here were chosen based on user needs. Future research is recommended to use a more advanced process for selecting a suitably broad, representative and meaningful set of species. Improved species-level results would arise from further refinement of the spatial land cover products; species habitat requirements; and availability of suitable habitat for specific iconic species, such as the koala (Rhodes 2020). The potential extent of occurrence for each chosen species could be refined to enable estimates of total changes in habitat remaining relative to the estimated area of original habitat (a firmer benchmark).

It is important to assess not only species-level biodiversity within ecosystem assets but also the genetic diversity of species and the diversity in species assemblages between ecosystem assets (i.e. the variation in the composition of assemblages, both within and between ecosystem types). The approach presented in this report does not capture genetic diversity. The basic framing of a species account could be adapted to present, for example, the extinction risk of phylogenetically diverse species or species groups. More research is needed to prepare data to assess the genetic level of biodiversity if this is relevant and a priority for the management of GKP.

Additional research could focus on linking community-level biodiversity data to ecosystem services, and linking the species-level biodiversity data to additional ecosystem services beyond the 'ecosystem and species appreciation' assessed in Chapter 6. In addition, and to support ecosystem management, the information on vascular plants could be decomposed into GKP's contribution to the maintenance of the diversity of vascular plants, compared to the contribution of areas that are beyond the boundary of GKP. This would give managers a more complete picture of how their actions are affecting biodiversity both in situ and beyond.

8.4 Accounting outputs

Species accounts and tables can be used to represent changes in species (for example, abundance), distribution or status/extinction risk over an accounting period. Species of interest include species important for ecosystem services; species of conservation concern; and species important for ecosystem condition (or functioning) (UNCEEA 2021).

The biodiversity assessments for 10 selected focal species show a range of results (Table 55 and Table 56), often varying markedly between species and ecosystem accounting areas. The species-level assessments aim to identify areas of suitable habitat within the potential extent of occurrence for each species (Table 54). They do not indicate where each species is expected to occur. Errors in the land cover classification, or in translating land cover categories to habitat suitability, may result in under- or over-estimation of areas of suitable habitat with the potential extent of occurrence. With these issues in mind, the focal species assessments vary considerably in terms of both their potential extent of occurrence, as well as the estimated areas of suitable habitat.

Within GKP, all focal species showed either no change or reductions in suitable habitat from 2010 to 2015. These trends in suitable habitat may be related to moisture availability, given 2015 was a much drier year than 2010 (annual precipitation at Gunbower in 2010 was 642 mm; 2015 was 249 mm (BOM 2020)). Reduced moisture availability may have influenced the coverage of land cover classes associated with 'suitable habitat' for the species considered, such as reduced tree cover, or reduced areas of aquatic vegetation.

Table 54 Estimated suitable habitat by species in the NSW and Victorian parts of Gunbower-Koondrook-Perricoota Forest Icon Site, 2010 to 2015

Suitable habitat	Unit	NSW-GKP									
		Australasian Bittern	Painted Honeyeater	Superb Parrot	Growling Grass Frog	Koala	Rigid Spider-Orchid	Winged Pepper-Cress	River Swamp Wallaby-Grass	River Red Gum	Black Box
Opening	`000 ha	0.42	27.67	27.67	0.42	27.67	24.79	26.59	0.42	17.07	16.84
Additions	`000 ha	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Unmanaged	`000 ha	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Managed	`000 ha	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Unknown	`000 ha	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Reductions	`000 ha	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Unmanaged	`000 ha	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Managed	`000 ha	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Unknown	`000 ha	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Net change	`000 ha	–	–13.11	–13.11	–	–13.11	–10.82	–12.43	–	–3.15	–3.16
Closing measure	`000 ha	0.42	14.56	14.56	0.42	14.56	13.97	14.16	0.42	13.92	13.67

Note: Areas are reported in thousands of ha. '–' = 0. NA = Not available with input data

Source: Mokany et al. (2021a, 2021b)

Table 54 continued

Suitable habitat	Unit	VIC-GKP									
		Australasian Bittern	Painted Honeyeater	Superb Parrot	Growling Grass Frog	Koala	Rigid Spider-Orchid	Winged Pepper-Cress	River Swamp Wallaby-Grass	River Red Gum	Black Box
Opening	`000 ha	0.02	17.06	17.06	0.02	17.06	15.15	16.66	0.02	27.68	27.58
Additions	`000 ha	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Unmanaged	`000 ha	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Managed	`000 ha	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Unknown	`000 ha	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Reductions	`000 ha	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Unmanaged	`000 ha	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Managed	`000 ha	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Unknown	`000 ha	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Net change	`000 ha	–	–3.13	–3.13	–	–3.13	–2.61	–2.88	–	–13.12	–13.10
Closing measure	`000 ha	0.02	13.93	13.93	0.02	13.93	12.54	13.78	0.02	14.56	14.47

Note: Areas are reported in thousands of ha. '–' = 0 NA = Not available with input data
Source: Mokany et al. (2021a, 2021b)

Table 55 Species-level biodiversity assessment in Gunbower-Koondrook-Perricoota Forest Icon Site, 2010 and 2015

Ecosystem accounting area	Unit	Australasian bittern (*Botaurus poiciloptilus*)				Painted honeyeater (*Grantiella picta*)				Superb parrot (*Polytelis swainsonii*)			
		Potential extent of occurrence	2010 habitat	2015 habitat	Change	Potential extent of occurrence	2010 habitat	2015 habitat	Change	Potential extent of occurrence	2010 habitat	2015 habitat	Change
NSW-GKP	`000 ha	34.95	0.42	0.42	–	34.95	27.67	14.56	−13.10	34.95	27.67	14.56	−13.10
VIC-GKP	`000 ha	21.07	0.02	0.02	–	21.07	17.06	13.93	−3.14	21.07	17.06	13.93	−3.14
All GKP	`000 ha	56.03	0.45	0.45	–	56.03	44.73	28.49	−16.24	56.03	44.73	28.49	−16.24

Note: Areas are reported in thousands of ha. '–' = 0

Source: Mokany et al. (2021a, 2021b)

Table 55 continued

Ecosystem accounting area	Unit	Growling grass frog (*Litoria raniformis*)				Koala (*Phascolarctos cinereus*)				Rigid spider-orchid (*Caladenia tensa*)			
		Potential extent of occurrence	2010 habitat	2015 habitat	Change	Potential extent of occurrence	2010 habitat	2015 habitat	Change	Potential extent of occurrence	2010 habitat	2015 habitat	Change
NSW-GKP	`000 ha	34.95	0.42	0.42	–	34.95	27.67	14.56	−13.10	31.71	24.79	13.97	−10.81
VIC-GKP	`000 ha	21.07	0.02	0.02	–	21.07	17.06	13.93	−3.14	18.94	15.15	12.54	−2.60
All GKP	`000 ha	56.03	0.45	0.45	–	56.03	44.73	28.49	−16.24	50.65	39.93	26.52	−13.42

Note: Areas are reported in thousands of ha. '–' = 0

Source: Mokany et al. (2021a, 2021b)

Table 55 continued

Ecosystem accounting area	Unit	Winged pepper-cress (*Lepidium monoplocoides*)				River swamp wallaby-grass (*Amphibromus fluitans*)				River red gum (*Eucalyptus camaldulensis*)				Black box (*Eucalyptus largiflorens*)			
		Potential extent of occurrence	2010 habitat	2015 habitat	Change	Potential extent of occurrence	2010 habitat	2015 habitat	Change	Potential extent of occurrence	2010 habitat	2015 habitat	Change	Potential extent of occurrence	2010 habitat	2015 habitat	Change
NSW-GKP	`000 ha	33.70	26.59	14.16	−12.43	34.95	0.42	0.42	–	34.96	17.07	13.92	−3.15	34.85	16.84	13.67	−3.16
VIC-GKP	`000 ha	21.07	16.66	13.78	−2.88	21.07	0.02	0.02	–	21.07	27.68	14.56	−13.12	20.82	27.58	14.47	−13.10
All GKP	`000 ha	54.77	43.25	27.94	−15.31	56.03	0.45	0.45	–	56.03	44.75	28.48	−16.27	55.68	44.41	28.15	−16.26

Note: Areas are reported in thousands of ha. '–' = 0

Source: Mokany et al. (2021a, 2021b)

Table 56 Species-level biodiversity assessment in Gunbower-Koondrook-Perricoota Forest Icon Site, by ecosystem type, 2010 and 2015

Ecosystem type	Unit	Australasian bittern (*Botaurus poiciloptilus*)				Painted honeyeater (*Grantiella picta*)				Superb parrot (*Polytelis swainsonii*)			
		Potential extent of occurrence	2010 habitat	2015 habitat	Change	Potential extent of occurrence	2010 habitat	2015 habitat	Change	Potential extent of occurrence	2010 habitat	2015 habitat	Change
Inland floodplain eucalypt forests and woodlands	`000 ha	47.154	0.293	0.244	-.049	47.154	38.744	24.026	-14.718	47.154	38.744	24.026	-14.718
Re-sprouter temperate and subtropical eucalypt woodlands	`000 ha	1.854	0.004	0.004	–	1.854	1.576	1.195	-0.381	1.854	1.576	1.195	-0.381
Fire-intolerant *Callitris* woodlands	`000 ha	0.457	–	–	–	0.457	0.082	0.022	-0.060	0.457	0.082	0.022	-0.060
Wetlands	`000 ha	4.875	0.142	0.192	.051	4.875	4.271	3.216	-1.055	4.875	4.271	3.216	-1.055
Lowland streams	`000 ha	1.125	0.008	0.007	-.002	1.125	–	–	–	1.125	–	–	–
Cultivated areas	`000 ha	0.334	–	–	–	0.334	–	0.004	0.004	0.334	–	0.004	0.004
Unclassified	`000 ha	0.226	–	–	–	0.226	0.056	0.027	-0.028	0.226	0.056	0.027	-0.028
All GKP	`000 ha	56.025	0.448	0.448	–	56.025	44.728	28.490	-16.238	56.025	44.728	28.490	-16.238

Note: Areas are reported in thousands of ha. '–' = 0
Source: Mokany et al. (2021a, 2021b)

Table 56 continued

Ecosystem type	Unit	Growling grass frog (*Litoria raniformis*)				Koala (*Phascolarctos cinereus*)				Rigid spider-orchid (*Caladenia tensa*)			
		Potential extent of occurrence	2010 habitat	2015 habitat	Change	Potential extent of occurrence	2010 habitat	2015 habitat	Change	Potential extent of occurrence	2010 habitat	2015 habitat	Change
Inland floodplain eucalypt forests and woodlands	`000 ha	47.154	0.293	0.244	-.049	47.154	38.744	24.026	-14.718	42.370	34.426	22.291	-12.136
Re-sprouter temperate and subtropical eucalypt woodlands	`000 ha	1.854	0.004	0.004	–	1.854	1.576	1.195	-0.381	1.854	1.575	1.194	-0.381
Fire-intolerant *Callitris* woodlands	`000 ha	0.457	–	–	–	0.457	0.082	0.022	-0.060	0.417	0.070	0.020	-0.051
Wetlands	`000 ha	4.875	0.142	0.192	.051	4.875	4.271	3.216	-1.055	4.453	3.818	2.988	-0.830
Lowland streams	`000 ha	1.125	0.008	0.007	-.002	1.125	–	–	–	1.098	–	–	–
Cultivated areas	`000 ha	0.334	–	–	–	0.334	–	0.004	0.004	0.263	–	0.003	0.003
Unclassified	`000 ha	0.226	–	–	–	0.226	0.056	0.027	-0.028	0.192	0.045	0.023	-0.022
All GKP	`000 ha	56.025	0.448	0.448	–	56.025	44.728	28.490	-16.238	50.646	39.935	26.518	-13.417

Note: Areas are reported in thousands of ha. '–' = 0
Source: Mokany et al. (2021a, 2021b)

Table 56 continued

Ecosystem type	Unit	Winged pepper-cress (*Lepidium monoplocoides*)				River swamp wallaby-grass (*Amphibromus fluitans*)			
		Potential extent of occurrence	2010 habitat	2015 habitat	Change	Potential extent of occurrence	2010 habitat	2015 habitat	Change
Inland floodplain eucalypt forests and woodlands	`000 ha	46.250	37.608	23.596	-14.013	47.154	0.293	0.244	-0.049
Re-sprouter temperate and subtropical eucalypt woodlands	`000 ha	1.854	1.575	1.194	-0.381	1.854	0.004	0.004	–
Fire-intolerant *Callitris* woodlands	`000 ha	0.457	0.082	0.022	-0.060	0.457	–	–	–
Wetlands	`000 ha	4.563	3.940	3.104	-0.836	4.875	0.142	0.192	0.051
Lowland streams	`000 ha	1.122	–	–	–	1.125	0.008	0.007	-0.002
Cultivated areas	`000 ha	0.333	–	0.003	0.003	0.334	–	–	–
Unclassified	`000 ha	0.187	0.050	0.025	-0.025	0.226	–	–	–
All GKP	`000 ha	54.766	43.255	27.944	-15.311	56.025	0.448	0.448	–

Note: Areas are reported in thousands of ha. '–' = 0

Source: Mokany et al. (2021a, 2021b)

Table 56 continued

Ecosystem type	Unit	River red gum (*Eucalyptus camaldulensis*)				Black box (*Eucalyptus largiflorens*)			
		Potential extent of occurrence	2010 habitat	2015 habitat	Change	Potential extent of occurrence	2010 habitat	2015 habitat	Change
Inland floodplain eucalypt forests and woodlands	`000 ha	47.154	38.596	23.665	-14.931	46.871	38.286	23.357	-14.930
Re-sprouter temperate and subtropical eucalypt woodlands	`000 ha	1.854	1.573	1.179	-0.394	1.852	1.570	1.176	-0.394
Fire-intolerant *Callitris* woodlands	`000 ha	0.457	0.112	0.044	-0.069	0.456	0.111	0.044	-0.068
Wetlands	`000 ha	4.875	3.849	3.065	-0.785	4.857	3.835	3.054	-0.781
Lowland streams	`000 ha	1.125	0.523	0.461	-0.062	1.081	0.509	0.447	-0.063
Cultivated areas	`000 ha	0.334	0.042	0.041	-0.001	0.334	0.042	0.041	-0.001
Unclassified	`000 ha	0.226	0.059	0.029	-0.029	0.225	0.058	0.028	-0.030
All GKP	`000 ha	56.025	44.753	28.483	-16.270	55.676	44.411	28.146	-16.265

Note: Areas are reported in thousands of ha. '–' = 0
Source: Mokany et al. (2021a, 2021b)

For waterbird species, the expected average species richness per ~90 m grid cell within GKP was higher for the Victorian jurisdiction than for the NSW jurisdiction (see Table 57). Expected average species richness within GKP was greater in 2010 than in 2015, likely due to the wetter conditions in 2010 better supporting waterbird species assemblages (annual precipitation at Gunbower in 2010 was 642 mm; 2015 was 249 mm (BOM 2020)). These estimated reductions in average waterbird species richness at GKP align with independent assessment of decreasing trends in waterbird populations over this period (Clemens et al. 2019). Table 58 reports results by ecosystem type, and Figure 39 shows a map.

Table 57 Community-level biodiversity assessment for waterbirds in Gunbower-Koondrook-Perricoota Forest Icon Site

Ecosystem accounting area	Average number of species		
	2010	2015	Change
NSW-GKP	16.88	16.27	–0.61
VIC-GKP	17.30	17.04	–0.26
All GKP	17.04	16.56	–0.48

Note: The average number of waterbird species expected per ≈90 m grid cell within each ecosystem accounting area.
Source: Mokany et al. (2021a, 2021b)

Table 58 Community-level biodiversity assessment for waterbirds in Gunbower-Koondrook-Perricoota Forest Icon Site, by ecosystem type

Ecosystem type	Average number of species		
	2010	2015	Change
Inland floodplain eucalypt forests and woodlands	16.80	16.37	–0.43
Re-sprouter temperate and subtropical eucalypt woodlands	18.76	18.44	–0.32
Fire-intolerant *Callitris* woodlands	17.24	16.58	–0.66
Wetlands	17.26	16.27	–0.99
Lowland streams	23.68	24.03	+0.35
Cultivated areas	14.92	14.94	+0.02
Unclassified	16.96	17.20	+0.24

Note: The average number of waterbird species expected per ≈90 m grid cell within each ecosystem type
Source: Mokany et al. (2021a, 2021b)

Approximately 85% of the vascular plant species originally occurring in GKP are expected to persist in the long term anywhere across their range, given changes in habitat condition over south-east Australia between 2010 and 2015 (Table 59). Impacts on estimated plant species persistence result not only from some habitat modification within GKP, but also from habitat loss and modification in the surrounding areas. Many of the species that occur within GKP require this broader habitat beyond GKP to maintain viable populations.

Within GKP no notable difference in plant species persistence between the NSW and Victorian jurisdictions (Table 59) was detected, and only minor differences were observed between ecosystem types (Table 60). Figure 40 maps the vascular plant persistence across all of GKP.

Table 59 Community-level biodiversity assessment for vascular plants in Gunbower-Koondrook-Perricoota Forest Icon Site

Ecosystem accounting area	Expected species persistence (%)		
	2010	2015	Change
NSW-GKP	84.9	85.1	+0.2
VIC-GKP	84.9	85.0	+0.1
All GKP	**84.9**	**85.1**	**+0.2**

Note: The percentage of species originally occurring within the ecosystem accounting area that are expected to persist over the long term anywhere in their range, given changes in habitat condition across all south-east Australia.
Source: Mokany et al. (2021a, 2021b)

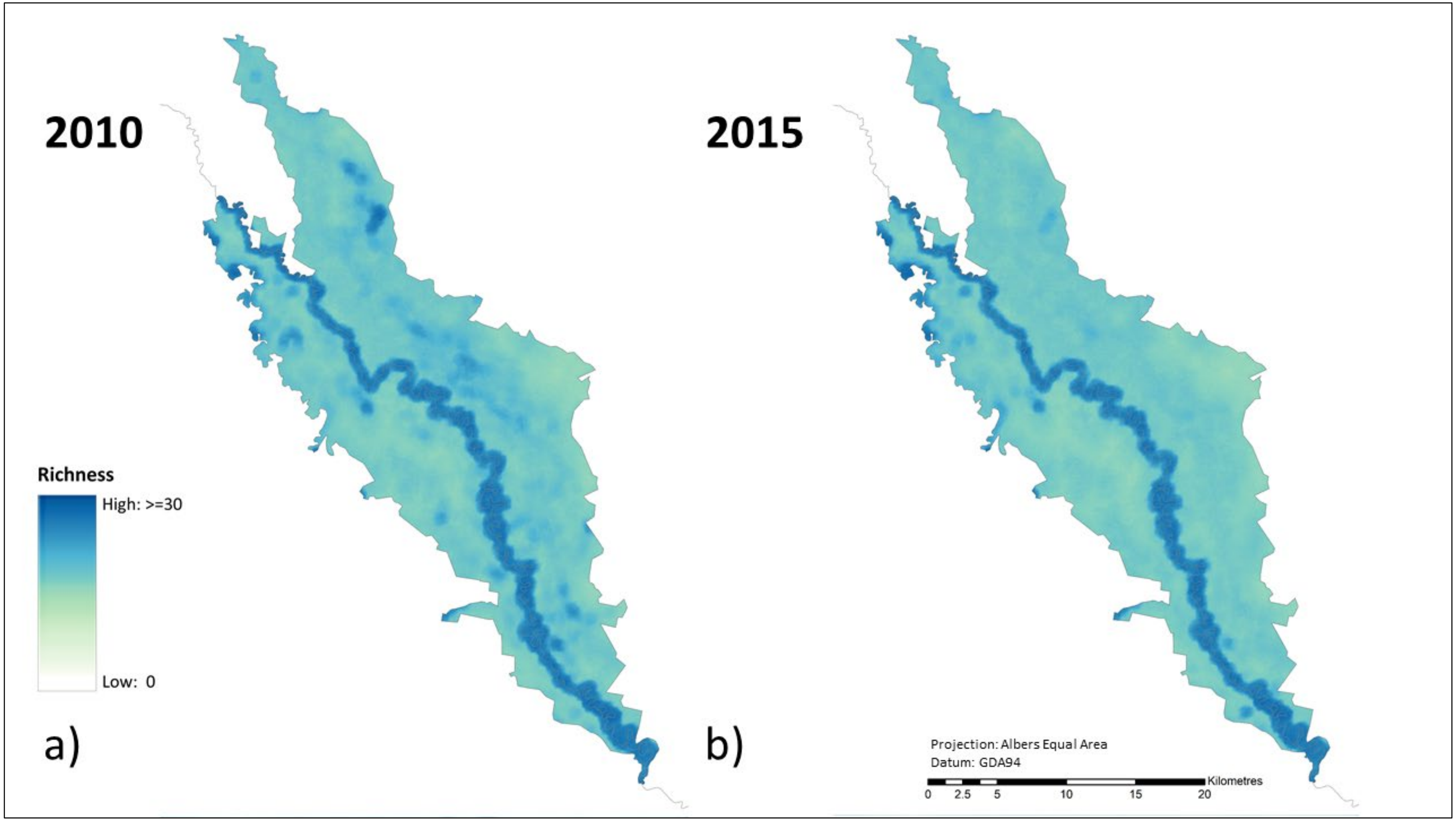
Only a very minor positive change in estimated plant species persistence was estimated for GKP from 2010 to 2015. This can be interpreted as meaning that the number of species expected to persist over the long term (i.e. well beyond 2015), given the current extent and condition of habitat, was slightly higher when assessed in 2015 than it was in 2010. This slight increase in estimated plant species persistence for GKP is likely due to wetter conditions in the 10-year epoch preceding 2015, given the HCAS estimates of habitat condition used data from the 10 years preceding each accounting year (Harwood et al. 2021a). Some minor influence of climate conditions in the HCAS estimates of habitat condition for biodiversity would result in the drier 10 years preceding 2010 having a slightly lower estimated habitat condition than the wetter 10 years preceding 2015 (for example, average annual precipitation at Gunbower for 2001 to 2010 was 341 mm/year; 2006 to 2015 was 352 mm/year (BOM 2020)). Further discussion of these aspects of the epochs in HCAS are provided in the HCAS technical report (Williams et al. 2021).

Table 60 Community-level biodiversity assessment for vascular plants in Gunbower-Koondrook-Perricoota Forest Icon Site, reported by ecosystem type

Ecosystem type	Expected species persistence (%)		
	2010	2015	Change
Inland floodplain eucalypt forests and woodlands	84.9	85.1	+0.2
Re-sprouter temperate and subtropical eucalypt woodlands	84.6	84.8	+0.2
Fire-intolerant *Callitris* woodlands	84.9	85.0	+0.1
Wetlands	85.0	85.2	+0.2
Lowland streams	84.2	84.3	+0.1
Cultivated areas	84.8	85.0	+0.2
Unclassified	85.0	85.2	+0.2

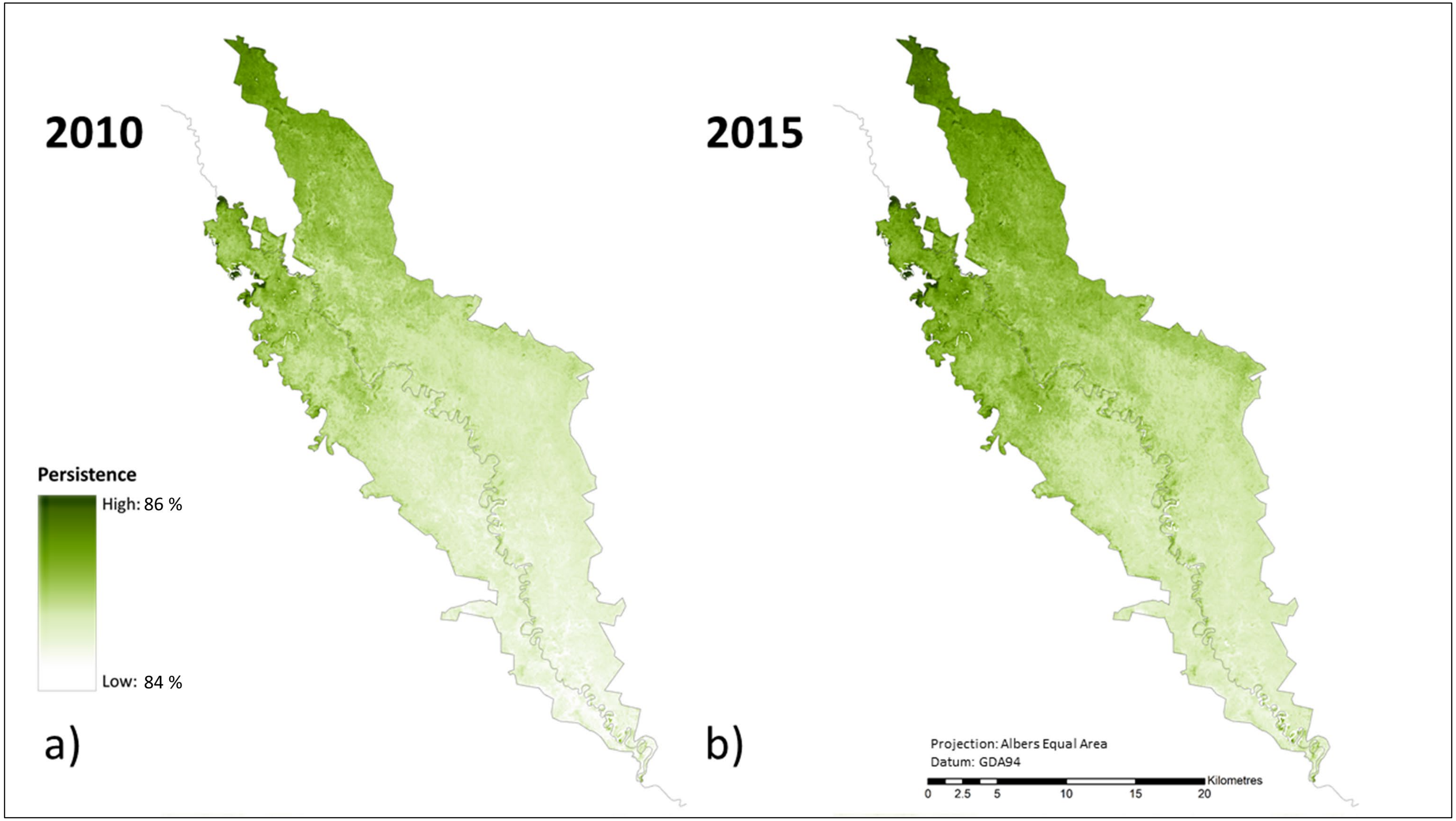
Note: 'Expected species persistence' is defined as the percentage of species originally occurring within the ecosystem accounting area that are expected to persist over the long term anywhere in their range, given changes in habitat condition across all south-east Australia.
Source: Mokany et al. (2021a, 2021b)

Figure 39 Expected waterbird species richness in each location (≈90 m grid cell) across Gunbower-Koondrook-Perricoota Forest Icon Site for a) 2010 and b) 2015



Source: Mokany et al. (2021a, 2021b)

Figure 40 Expected persistence of vascular plant species in each location across Gunbower-Koondrook-Perricoota Forest Icon Site for a) 2010 and b) 2015



Note: 'Expected species persistence' is defined as the percentage of species originally occurring within the ecosystem accounting area that are expected to persist over the long term anywhere in their range, given changes in habitat condition across all south-east Australia.
Source: Mokany et al. (2021a, 2021b)

9 Integration, coherence and analysis

Integration and coherence are important in environmental-economic accounting. This chapter defines these terms, and then assesses the coherence of the concepts, data and methods underpinning the accounts presented in this report. Lastly, the chapter describes three analyses of the accounts and data presented in Chapter 4 to Chapter 8.

9.1 Definitions and framing

Integration and coherence are central to understanding the potential contribution of ecosystem accounting to statistical outputs and decision making. Box 20 provides definitions of coherence and integration. The distinction between coherence and integration is important: integration is a process while coherence is a quality or state.

Box 20 Integration and coherence

Integration – the act or process of uniting different concepts, methods, models and datasets

Coherence – the quality or state of cohering: such as a systematic or logical connection or to be logically consistent

This project integrated concepts, models, methods and data with the aim of coherence. Coherence relies on this integration and may be limited by the quality of the elements that are being integrated and the approach to integration. The process of integration requires scientists, accountants and economists to understand how different models and concepts work together and achieve a shared understanding of what coherence means when undertaking environmental-economic accounting. Table 61 shows examples of integration that have resulted in a coherent outcome.

Table 61 Examples of integration leading to coherence for environmental-economic accounting

Elements	Integration	Coherence
Concepts	Concepts around the environment and economy (System of National Accounts (SNA)) have been integrated by working groups in the UNCEEA.	The core accounting model (as a reflection of a capitals approach) describes the conceptual linkages between the environment and the economy (SNA), and is coherent with the SNA.
Models / Methods	1) For the environment, conceptual models of the five ecosystems found in GKP were developed based on the Australian Ecosystem Models Framework (Richards et al., 2020). 2) Using the methods described in Richards et al. (2021c), these were integrated into a state and transition model of all the ecosystems in the GKP. 3) The state and transition model was integrated with the core accounting model.	Integration has delivered coherence in models within and between disciplines. Integration has produced an approach that allows for data to be consistent across different scales and time periods.
Data	Environmental and economic data are integrated based on the guidelines, treatments and definitions contained in the SEEA EA.	The data are account ready following the SEEA EA. Datasets are now coherent and can be compared, combined, integrated and analysed.

9.2 Coherence of concepts

Ecosystem accounting operates at the nexus of economics and ecology. Generally speaking, economics is the study of human behaviour and the choices people make, while ecology is the study of organisms and how they interact within their environment.

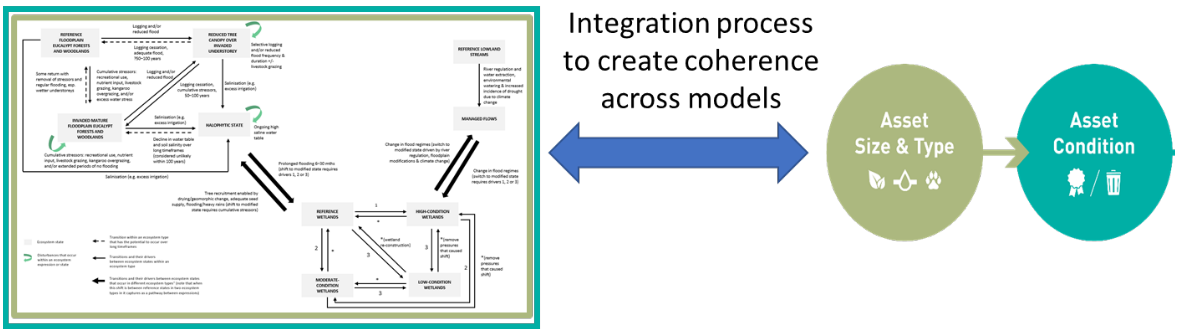
Working across the two disciplines can be challenging. For example, in ecology it is often difficult to distinguish between natural changes and changes that result from human actions. In addition, all people including economists and ecologists, have varying worldviews and will value the environment in different ways. For example, are ecosystems instrumentally valuable because of the services that they provide to humans? Or are they intrinsically valuable because of their ability to function (their ecological integrity)?

The core ecosystem accounting framework in the SEEA EA provides a conceptual framework that links the environment and the economy using the concepts of stocks (ecosystem extent and condition) and flows (ecosystem services and benefits). The framework provides a common framing for policy-makers, scientists and economists with respect to recording information about ecosystems and their management as assets. Depending on how people value the environment, they may focus on ecosystem services and benefits that are generated by the assets and used by people, or on the intrinsic values of ecosystems and therefore only on the ecosystem asset extent and its condition.

Ecological conceptual models have been developed during this project for GKP (Richards et al. 2021c). These ecological conceptual models emphasise the dynamic nature of ecosystems through the articulation of ecosystem types, states and expressions. They also consider drivers (for example, prolonged flooding, which could be driven by environmental watering) that may contribute to shifts between the different ecosystem expressions and transitions between ecosystem states. This enables the disentangling of impacts of management actions from natural variation, and the attribution of changes in ecosystem extent to either managed or unmanaged expansions and reductions in area (see example in the ecosystem extent account in Table 8).

A key contribution of this project was to develop coherence between the ecological conceptual models and the core ecosystem accounting framework. The ecological conceptualisation represents the extent and condition components of the accounting framework (Figure 41). An example of the integration that occurred concerns the link between the concept of ecosystem states in the dynamic conceptual model of ecosystems and the concept of ecosystem condition as described in the SEEA EA accounting guidelines, treatments and definitions.

Figure 41 The ecological conceptual models represent the asset type and condition in the core accounting framework

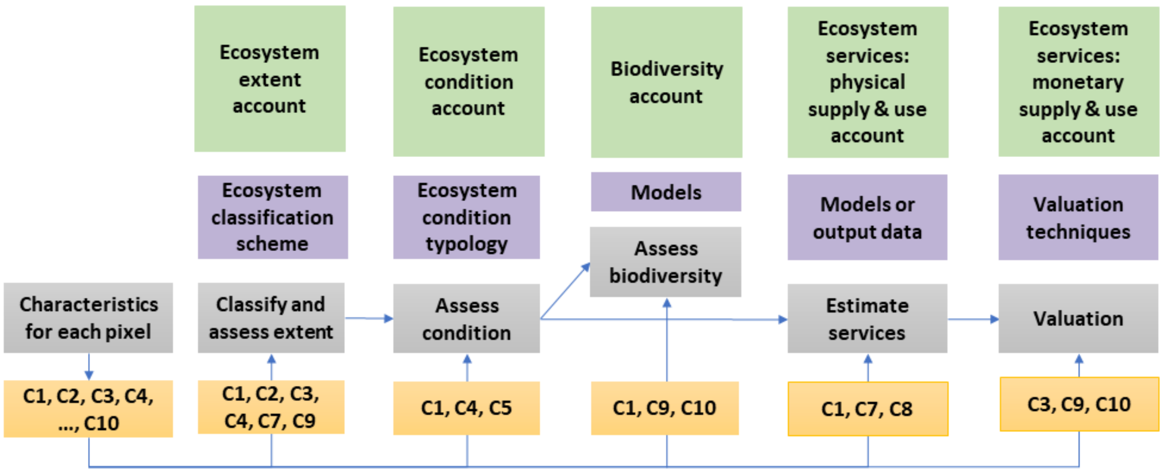


Combining different concepts and perspectives can be difficult and there is an integration cost when new concepts are developed. At the same time, once a conceptual integration and understanding has been reached, there is significant potential to broaden the use and application of data. A review of concepts will be useful to design or select models that can be integrated easily to achieve coherence in the future.

9.3 Coherence of methods and models

The integration of concepts provides the basis for meaningfully integrating and interpreting methods and models from ecological and economic domains. For ecological conceptual models to link with the accounting framework in practice there needs to be a common understanding of the ecosystem characteristics used to assess extent, condition, biodiversity and services (Figure 42).

Figure 42 Linking ecosystem characteristics across the core framework



Note: 'C' refers to different generic ecosystem characteristics. See Figure 49 for the source datasets for these ecosystem characteristics.

While coherence in models and methods is difficult to achieve there have been efforts as part of this project to integrate them. In short, the ecological conceptual models include ecosystem condition characteristics which can be used to estimate ecosystem services. In accounting terms, having the characteristics to estimate ecosystem services is central to understanding environmental and economic transactions. Essentially it is important to have a clear understanding of the characteristics shown in Figure 42 by the ecologists, economists and accountants to ensure coherence of models and methods.

The core accounting framework requires a set of characteristics to spatially delineate ecosystems, as an input to condition accounts and as inputs to estimate (or model) flows of ecosystem services. The accounting process should be undertaken interdependently, not in a linear fashion. Coordination between ecologists, economists and accountants from the outset of the project is key to ensuring characteristics used in ecological models can be used as inputs into economic models.

There is also a need for ecosystem characteristics to be linked to management drivers, climate variability or other environmental pressures. Understanding the ecosystem characteristics that support the provision of ecosystem services is critical for linking ecosystem conceptual models to the quantification of ecosystem services. In this project we used state and transition models to conceptually align ecosystem drivers (captured as transitions between states or shifts between ecosystem expressions) with ecosystem characteristics relevant for quantification of ecosystem services.

Coherence of models and methods across different spatial scales, spatial areas and time periods is also important. Ecosystem accounting aims to provide a scalable story, enabling each site to be compared to an aggregate or average figure that is representative of some broader context. For example, GKP can be considered within the broader context of the Murray-Darling Basin (MDB) across extent, condition, services and benefits and contextual information provides a sense of the importance of GKP within a broader system. For example, a companion technical report (Mokany et al. 2021a) presents biodiversity data for the whole of the Murray-Darling Basin for context.

Coherence between different spatial areas is important for similar reasons as it enables comparisons to be made. For example, from the perspective of the management of wetlands across the MDB, it may be important to compare a wetland in one location to another to allocate resources across the landscape. At a fine scale, comparisons can be made across ecosystem types in different locations, ecosystem assets can be compared within a location and so on. Application of a consistent method enables these comparisons to be made.

Coherence across different time periods provides comparable information across time. An agreed approach and consistent data is required to enable coherence across time. In some cases, new datasets may become available or new methods may be employed. This can cause differences in numbers over time. Hindcasting can be used to ensure coherence across time when new methods are used. However, when new data is used that cannot be used in a previous period an alternative approach may be required. It may be necessary to assess changes because of a method change.

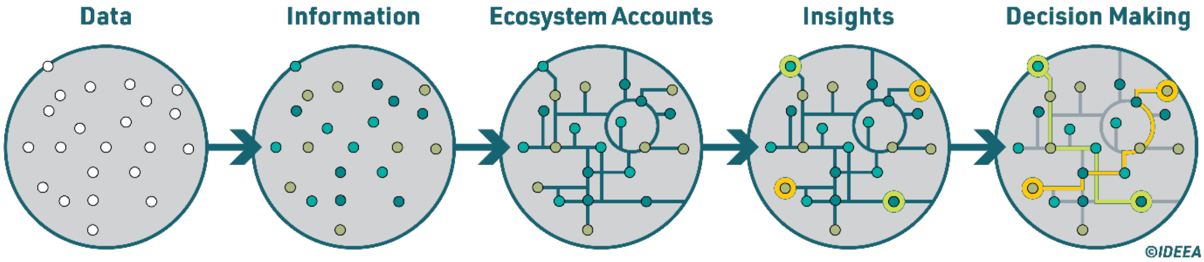
9.4 Data

The SEEA EA accounting guidelines, treatments and definitions were used to integrate ecological information so it is coherent and account ready.

In the context of accounting, integration is a process for organising data to produce a coherent set of information that can be used in accounts. This set of coherent information can then be interpreted and analysed in different ways. The utility of the accounts for different applications relies, in part, on the degree to which the information set is coherent.

Coherence of data reflects the degree to which the data, which has been through a process of integration, are logically connected and complete. Figure 43 shows a stylised process for integration of data into a coherent information set for accounting and decision-making, where the colours of the information reflect the 4 components of the core accounting framework. Relevant questions related to data coherence include whether the full spectrum of ecosystem condition characteristics required for assessing ecosystem services has been collated, and whether one sees a change in the quantity of ecosystem services when there is a change in ecosystem condition characteristics. There is also a link between measures of ecosystem integrity (for example, via an ecosystem condition index) and ecosystem services. For example, a minimal departure of ecosystem condition from the reference state (a high ecosystem condition index score) might be linked to recreation services where people are seeking to experience natural ecosystems. However, provisioning ecosystem services (such as timber provision) may rely on (or cause/ result in) a larger departure of ecosystem condition from a reference (i.e. a lower ecosystem condition index score), highlighting a trade-off between sets of ecosystem services. In the state and transition model framing, this is described as a transition to a different ecosystem state. Here, the underpinning ecosystem condition characteristics of an ecosystem state enable a quantification of changes to the supply of ecosystem services (such as recreation, carbon sequestration and stock, timber etc.).

Figure 43 Integration to create coherent information for decision-making



Accounts based on coherent data sets can be more confidently used to inform decision making. Different components of the accounting information can be analysed simultaneously to produce insights. For example, an insight may include observing changes in the condition of an ecosystem and how that has had an impact on ecosystem services, whereas previously these datasets were examined in isolation and the connection (that is, the insight) could not be made. The value of the insights will be greater when there is a greater level of coherence in the datasets. It is possible to undertake integration and create accounts and tables with non-coherent data, but the results will not be as robust for decision-making.

These insights are additional to the information gained from analysing individual accounts, because they are based on the relationships between different accounting components (for example, assets, condition, biodiversity, services, benefits and management actions and drivers).

9.5 Analysis of accounts and data

The concepts and definitions of ecosystem accounting described in the SEEA EA (UNCEEA 2021), along with the quality of data inputs and integration methods, provide an approach to producing coherent data. The data can be summarised into ecosystem accounts or used in other applications. The value-add of ecosystem accounting is therefore twofold: (i) the production of coherent data that can be used in multiple applications (requiring additional effort to perform the application), and (ii) the production of ecosystem accounts.

The accounts can be analysed in isolation or simultaneously to produce insights including:

- ecosystem information, including changes in extent and condition
- the relative performance of different ecosystem types and assets in terms of their output
- area-based measures of ecosystem service productivity.

The potential use of ecosystem accounts for decision making is illustrated in this section. With further refinement and additional analyses, information that has been produced can be linked to existing decision-making processes and applications (for example, scenario modelling and performance indicators).

To offer a practical illustration of the linkages to policy described in Section 2.5 (Interpretation of accounting outputs), we use three examples to show how accounting information can be used in decision making, and how integrated analysis of ecosystem extent, condition, biodiversity and services (physical and monetary) can support decision making. These three examples show how accounting information can be used to address the types of basic and complex policy questions in Table 6 of this report. We discuss:

- evaluating the impact of environmental watering (an example of 'Evaluate success of solution' using 'extent', 'condition' and 'physical supply and use')
- assessing bundles of ecosystem services from one location: timber (firewood, sawlog) and carbon stocks and sequestration (an example of 'design solution' using 'physical supply and use')
- assessing the current state of biodiversity as part of conserving protected areas and related ecosystem services (an example of 'problem diagnosis' using 'species-level biodiversity' linked with other account data).

9.6 Analysis example 1 – Environmental watering

9.6.1 Background

Ecosystems are complex with many drivers influencing their condition including water availability, climate variability, natural disturbances and human activity. Management regimes influence these drivers. The attribution of change to specific management interventions is an important objective for decision-makers. Conceptual models developed during this project provide a basis for understanding how ecosystems may respond to management interventions and climate. These hypothesised relationships need to be tested and validated empirically for ongoing use in decision making.

Information on ecosystem extent, condition, services and benefits provides the core information basis for attributing change. Information on drivers is also required to attribute change (for example, timing and extent of management actions, incidence and frequency of natural events such as droughts, etc.). Next steps include refining the way data is collected to construct a longitudinal dataset of appropriate dimensions for use in biophysical and econometric analysis to assess the causal relationship between management actions and outcomes for both ecosystems and society.

9.6.2 Example of integrated analysis: environmental watering

Here we provide an example of how environmental accounts could be used at GKP to analyse a specific management action, the environmental watering of icon sites, which is critical to maintaining ecosystem function of wetland and floodplain habitat in order to sustain ecological communities and promote reproduction and recruitment.

Natural flood events in 2010 and 2011 resulted in inundation of greater than 50% of the forest with flows above 45,000 ML per day for three peak events occurring in September 2010, January 2011 and February 2011. Further flows above 30,000 ML per day occurred in late 2011, 2012 and 2013, which also flooded parts of the forest. These events resulted in significant watering of the forest for the first time in over 10 years (VEWH 2013).

Between December 2011 and 2015 the Gunbower forest ecosystem was supported by regular environmental watering events from Living Murray and Victorian Environmental Water Holder allocations (Table 62). In Gunbower forests the watering events resulted in vegetation responses for the 'wetlands' and 'inland eucalypt forests and woodlands' ecosystem type. Responses were also seen for fish, waterbirds and maintenance of ecosystems (Table 62) (VEWH 2016).

Environmental watering in Koondrook-Perricoota forest has been limited to the end of the accounting period. Watering events in 2013−14 were delayed during construction of environmental watering structures. Monitoring of watering events in 2014−15 identified positive responses of floodplain and wetland vegetation, improved tree health and reduced encroachment of floodplain vegetation into wetlands (MDBA 2016) (Table 62). Allocations for Koondrook-Perricoota include NSW licensed environmental water, Living Murray, Commonwealth Environmental Water and environmental water allowance accrued under water sharing plans.

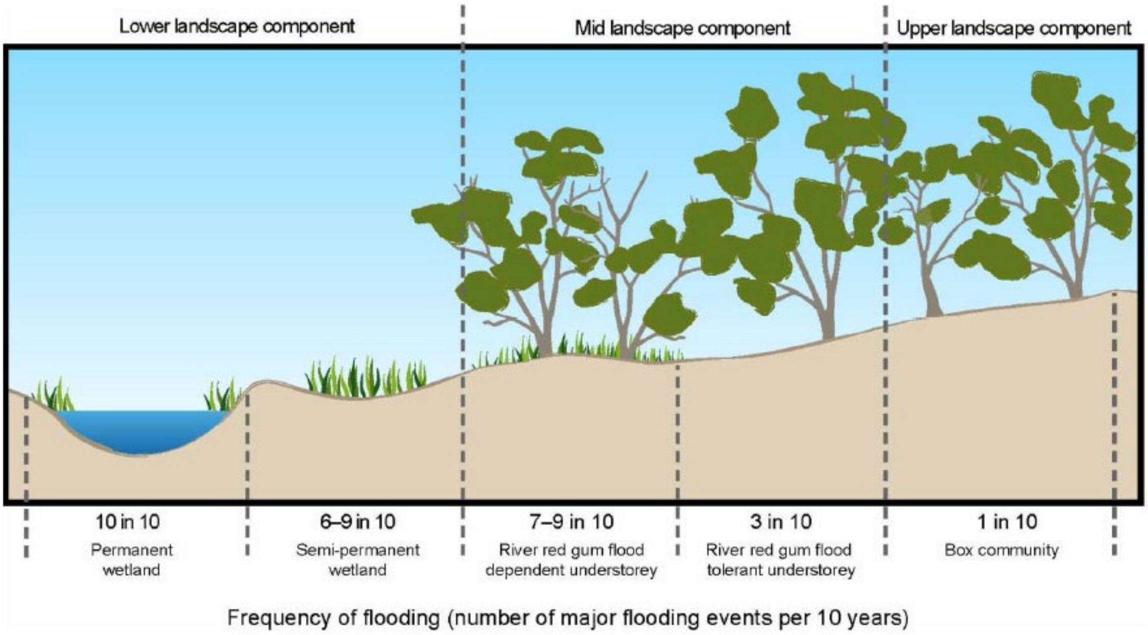
Table 62 Summary of environmental watering events and objectives for Gunbower and Koondrook-Perricoota forests from 2011 to 2016.

	Gunbower Forest			**Koondrook-Perricoota Forest**		
Year	**Volume (ML)**	**Area (ha)**	**Objective / response**	**Volume (ML)**	**Area (ha)**	**Objective / response**
2011−12	645	350	Maintain wetland water levels, waterbird breeding event	0	0	NA
2012−13	0	0	NA	0	0	NA
2013−14	19,257	ND	Recovery of native fish species	0	0	NA
2014−15	37,400	3,800	Redgum watering, wetland filling, fish movement between channel and floodplain	26,400	4,000	Understorey, semi-aquatic and aquatic vegetation growth. Reduced encroachment of terrestrial vegetation
2015−16	28,692	2,692	Mass small-bodied fish recruitment, recovery wetland vegetation and floodplain eucalypts	1,600	ND	Flooding of Pollack Swamp
Total	**85,994**	**6,842**	**NA**	**28,000**	**4,000**	**NA**

ND = not determined; NA = not applicable.
Source: MDBA (2014, 2015, 2016), NCCMA (2013), VEWH (2012, 2013, 2014, 2015, 2016)

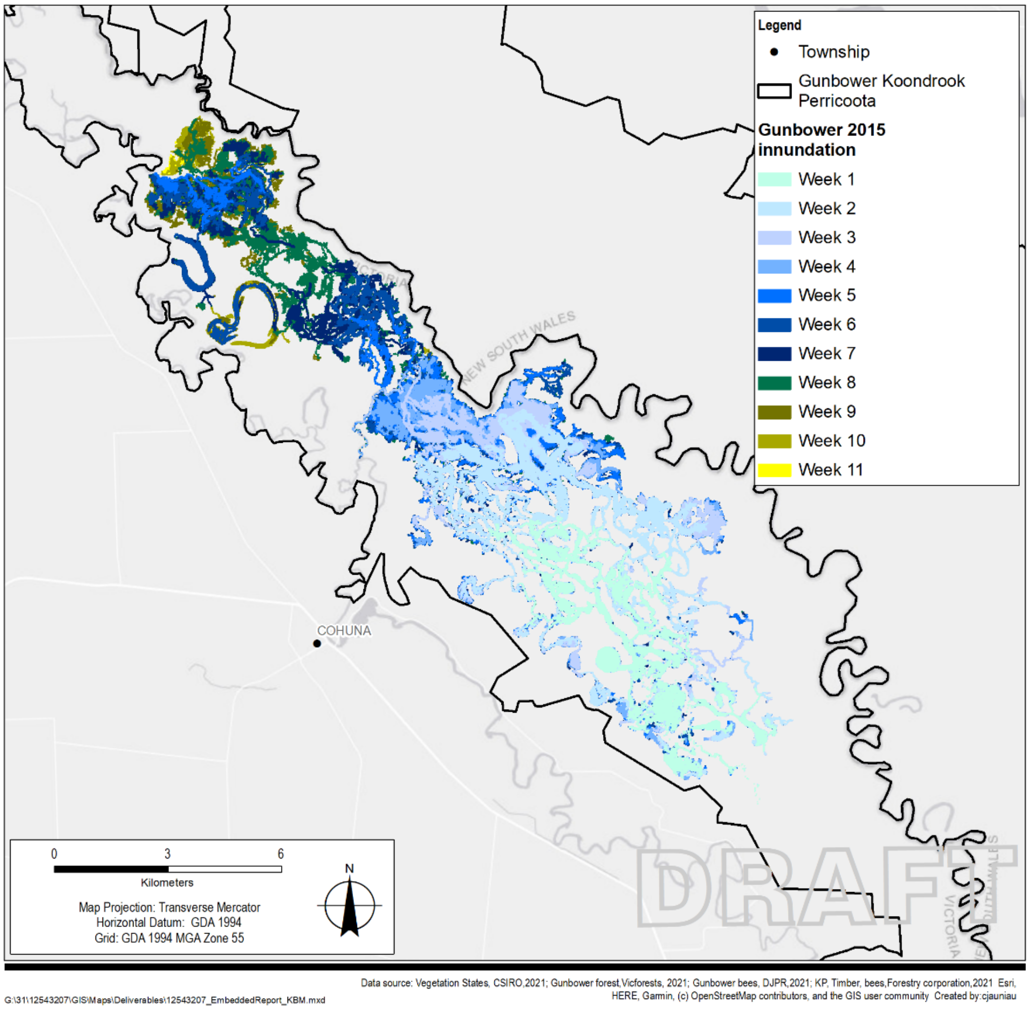
Environmental water requirements for GKP floodplains and wetlands vary depending on their location in the landscape, with increased frequency and duration of flooding required for wetlands and floodplain-dependent understorey vegetation (Figure 44). Duration of inundation varies from 7 to 12 months for wetlands, 1 to 8 months for flood-dependent understorey vegetation and less for communities higher in the landscape (Ecological Associates 2006). An example is the 2015 watering event where Gunbower wetlands were watered using a VEWH allocation of 28,692 ML over a ten-week period. The watering event, inundated 2,692 ha of floodplain communities: 183 ha wetlands (90% of wetlands in the forest); 2,090 ha 'invaded mature floodplain eucalypt forests and woodlands' modified state; and 419 ha of other modified states in the 'inland floodplain eucalypt forests and woodlands' ecosystem type (Figure 45). The majority of this water was retained in the landscape, with approximately 700 ML released into the River Murray via Shillinglaws regulator during the final 4 weeks. Post-event monitoring identified improved growth of river red gums, aquatic plant growth and mass recruitment of small-bodied fish (VEWH 2016). Monitoring of the progressive filling of wetlands and inundation of inland floodplain eucalypt forests and woodlands over the ten-week period is illustrated in Figure 45.

Figure 44 GKP frequency of environmental watering required for wetlands and floodplain vegetation



Note: The River Red Gum flood dependent and flood tolerant understories, and the Box community, are vegetation types that fall within the 'inland floodplain eucalypt woodlands and forests' ecosystem type. The permanent and semi-permanent wetlands are included in the 'wetlands' ecosystem type. Source: Ecological Associates (2006).

Figure 45 Gunbower 2015–16 environmental watering event, showing progressive inundation of 'wetlands' and 'inland floodplain eucalypt forests and woodlands' ecosystem types.



MDBA site condition monitoring of Gunbower forest has detected positive ecosystem responses to environmental watering with condition indices for vegetation, waterbirds and fish improving between 2010 and 2015 (MDBA 2018). Site condition monitoring of Koondrook-Perricoota has identified indices for vegetation, waterbirds and fish that are significantly lower than Gunbower and have not changed through the same time period (MDBA 2018).

Both natural flooding between 2011 and 2013 as well as environmental watering events have contributed to meeting environmental watering objectives for maintaining and improving ecological processes and communities in Gunbower forest (VEWH 2013, 2014, 2015). However, the benefits from, and ecological responses to, the most extensive environmental watering events in 2014–15 and 2015–16 were not able to be assessed in this case study because of the time lag in the expected ecological responses, which will occur in the years outside the accounting period. For example, watering prior to 2015 has not been sufficient to support apiary services and honey production, which was established through discussions with apiarists who reported zero supply in 2010 and 2015.

Future accounts can provide a longer time series of relevant biophysical and economic information. To assess the causal impacts of environmental watering, these accounts can be analysed in combination with the underpinning conceptual models; auxiliary datasets on drivers; and ecological and econometric analysis. In particular, this analysis would involve comparing different spatial areas and across time, and highlighting differences between extent, condition, services and benefits. Identification of these differences is important as a policy diagnostic, and also to recommend collection of data required to test hypotheses of causal links between watering and ecological responses. This extends the extensive research and monitoring programs already in place.

Future ecosystem accounts at GKP, and related applications and analysis, can help to assess benefits arising to the community from environmental water via a range of ecosystem services. 'Wetlands' and 'inland floodplain eucalypt forests and woodlands' ecosystem types would be expected to respond positively to more frequent environmental watering through increased health of wetland aquatic vegetation, forest and woodland plant species, waterbirds numbers and native fish recruitment.

Improved ecosystem condition is likely to increase the supply of ecosystem services including:

- carbon sequestration and stocks, through improved water regimes and more permanent bodies of water. Increased growth of terrestrial ecosystem types will increase carbon sequestration rates and stock.
- honey supply services, through improved groundwater levels supporting growth and reproduction of river red gum and black box eucalypt species
- increased river red gum growth to maintain timber yields
- improved ecosystem condition is likely to influence the supply of recreation and cultural services.

Building on the physical supply and use accounts, the monetary account information supports decision-making that seeks to optimise the balance of impacts across different stakeholders impacted by changes to environmental watering regimes.

Decision-makers are able to use the suite of quantified physical services and monetary benefits to weigh the relative impacts to beneficiaries. Combining the monetary supply and use accounts with other information enables comparison with other uses of the water, including domestic and agricultural consumption. The monetary asset value information can also underpin estimates of the social and economic costs and benefits of enhancement or degradation of the system.

9.7 Analysis example 2 - Assessing bundles of ecosystem services

9.7.1 Background

Natural capital managers (foresters, apiarists, public asset managers) regularly make decisions across the landscape. Managers will use criteria and best-practice management to maintain or improve ecosystem extent and condition and provide value to society. However, information on both extent and condition is often incomplete and the linkages between ecosystems and society are poorly understood. In this context, ecosystem accounts for GKP provide an enhanced set of information on the extent, condition and services GKP provides to the community to support decision making.

The linking of ecosystems to people is made possible by the concept of ecosystem services. Quantitative information on ecosystem services is a key input in an adaptive management approach that focusses on the outcomes and impacts of management actions. Information on ecosystem services can be used in many parts of the adaptive management approach (which consists of seven steps: scope, plan, do, monitor evaluate, report and adjust). For example, information on ecosystem services can be an input to planning when optimising and prioritising ecosystem service provision and management regimes across the landscape. Ongoing ecosystem accounts can also be used to monitor the effectiveness of management practices and ecosystems spatially. For example, decision-makers can use the concept of ecosystem services to monitor the productivity of ecosystems with respect to the benefits (private and public) that are being provided, and whether the delivery of ecosystem services matches intentions or deliver desired benefits.

9.7.2 Integration example – small timber coupe in Gunbower

This example examines how the bundling of ecosystem services, set within a state and transition modelling framework, enable an exploration of trade-offs and benefits of different management actions, related to silviculture and river regulation, on the supply of ecosystem services. The example is based on timber harvesting coupes logged in 2015 in Gunbower Forest. The area logged included a variety of ecosystem states of the 'inland floodplain eucalypt forests and woodlands' ecosystem type.

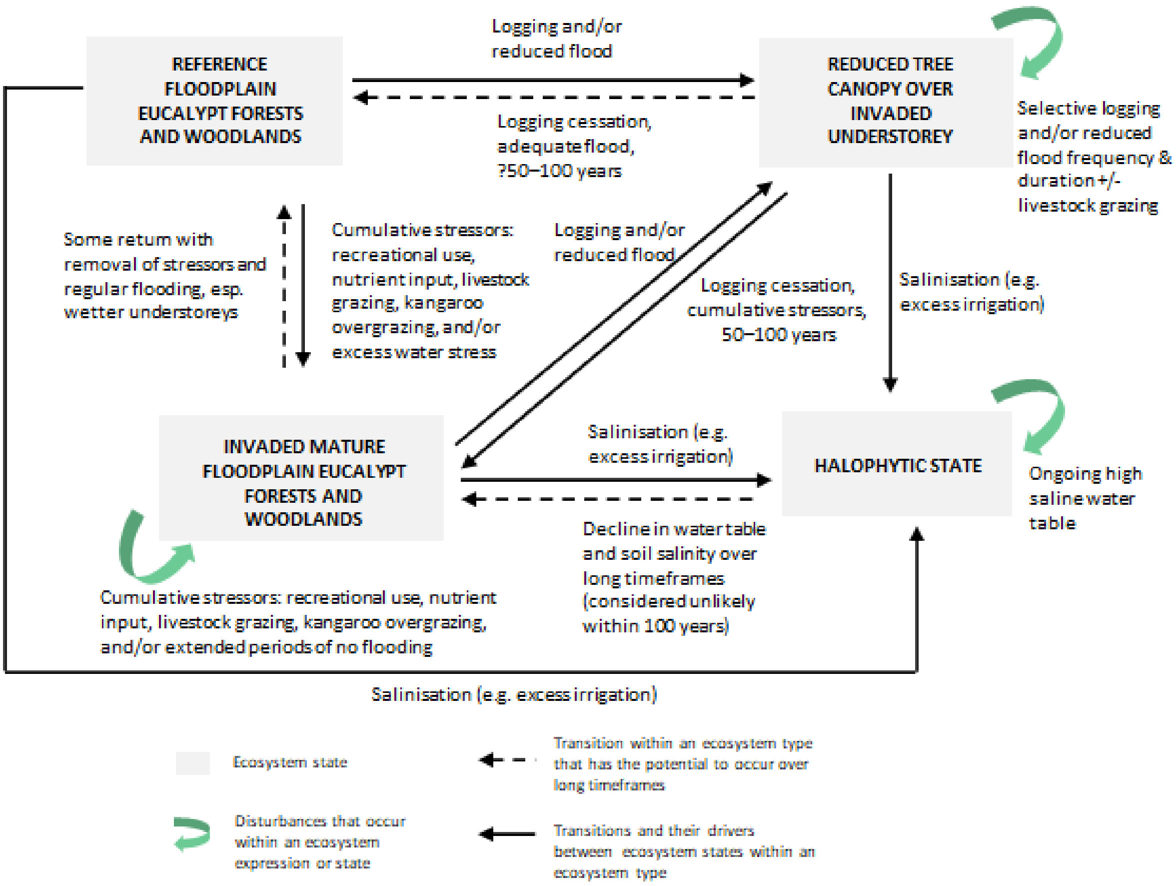
'Inland floodplain eucalypt forests and woodlands' is the dominant ecosystem type at GKP and ranges in structure from high- to moderate-density open eucalypt forests where regularly inundated, to open eucalypt woodlands on drier floodplains. In GKP, this range involves a shift in the dominant eucalypt from river red gum (*Eucalyptus camaldulensis*) to black box (*E. largiflorens*) and sometimes grey box (*E. microcarpa*). The reference state in this ecosystem type is dominated by the 'mature floodplain eucalypt forests and woodlands' expression, which has an average aboveground biomass of 226 t ha^{-1}, 40% canopy cover, 72 stems ha^{-1} and an average stem diameter of 0.4 m.

Timber harvesting and/or long periods of inadequate groundwater, flooding and rainfall can result in patchy or extensive loss of mature eucalypts from the reference state and invaded mature floodplain eucalypt forests and woodlands states leading to a transition to the reduced tree canopy over invaded understorey state. In this state, aboveground biomass is 107 t ha^{-1}, canopy cover is 30%, stem density is 67 stems ha^{-1} and average stem diameter is 0.3 m. The understorey may contain species tolerant of regular flooding or those adapted to drier conditions and is often invaded by exotic plants (although still typically includes hardy and colonising native plant species). Dominance of the 'reduced tree canopy over invaded understorey' expression in the landscape, a key expression in the 'reduced canopy over invaded understorey' state, is driven by selective logging, ringbarking and/or reduced water availability, with or without livestock grazing.

Rising saline groundwater, caused by excess irrigation in agricultural areas surrounding GKP, can also result in a transition from any state in the 'inland floodplain eucalypt forests and woodlands' ecosystem type to the 'halophytic' modified state. If high-saline water tables remain for extended periods of time, this state becomes dominated by an 'invaded halophytic shrubland' expression with dead trees persisting for a number of years. Average height of the upper vegetated layer in this state is 1 m, canopy cover of this layer is 35%, and aboveground biomass is low (although there is no published information on aboveground biomass in this state).

A summary of the states and transitions in the 'inland floodplain eucalypt forests and woodlands' ecosystem type is shown in Figure 46 and images of each state in Figure 47. Ecosystem conceptual models identified timber harvesting as a driver of transitions between states and ongoing selective logging maintain this ecosystem type in the lower condition state 'reduced tree canopy over invaded understorey' (Figure 46).

Figure 46 State and transition model of the 'inland floodplain eucalypt forests and woodlands' ecosystem type at GKP



Source: Richards et al. (2021c)

Figure 47 Images of each ecosystem state in the ‘inland floodplain eucalypt forests and woodlands’ ecosystem type

Note: A) reference state; B) ‘reduced tree canopy over invaded understorey’ modified state; C) ‘invaded mature floodplain eucalypt forests and woodlands’ modified state; D) ‘halophytic’ modified state. Image credits: S. Prober and P. McInerney. Source: Richards et al. (2021c)

Flows of ecosystem services from the ‘inland floodplain eucalypt forests and woodlands’ ecosystem type can be quantified by the ecosystem characteristics and extent of the states and expressions that make up this ecosystem type. Table 63 describes the range or bundle of services that flow from each ecosystem state in the ‘inland floodplain eucalypt forests and woodlands’ ecosystem type, and the ecosystem condition index (ecological integrity) of each state in timber harvesting coupes in Gunbower in 2015. Carbon sequestration and stock estimates were calculated for 2015 with and without logging. Carbon estimates post logging identified reductions in carbon stock and sequestration estimates of:

- 33% for ‘reduced tree canopy over invaded understorey’ modified state; and
- 17% for ‘invaded mature floodplain eucalypt forests and woodlands’ modified state and combination ‘reduced tree canopy over invaded understorey and invaded mature floodplain eucalypt forests and woodlands’ modified state.

Table 63 Extent, condition and flow of ecosystem services for each ecosystem state in the 'inland floodplain eucalypt forests and woodlands' ecosystem type for timber harvesting coupes at Gunbower in 2015

Ecosystem state	Reduced tree canopy over invaded understorey	Invaded mature floodplain eucalypt forests and woodlands	Halophytic state	Reduced tree canopy or invaded mature*
Area (ha)	7	51	1	47
Ecosystem condition index	0.46	0.58	0.16	0.50
Timber (tonnes ha^{-1})	6.4	6.5	–	6.6
Firewood (tonnes ha^{-1})	32	32.6	–	32.7
Carbon sequestered no logging (tonnes carbon ha^{-1} yr^{-1})	20.6	22.0	3.0	21.0
Carbon sequestered post timber harvest (tonnes carbon ha^{-1} yr^{-1})	13.8	18.3	2.2	17.4
Carbon stored no logging (tonnes carbon ha^{-1})	102	108	16	102
Carbon stored post timber harvest (tonnes carbon ha^{-1})	68.3	89.6	13	84.7

Note: Carbon sequestration and stock reductions post logging are based on estimated proportion of total above ground biomass removed due to logging occurring in the defined coupe areas. Estimates do not include projected increased sequestration from vegetation regeneration. '–' = 0. Based on values calculated for 2015
*In this area, the extent of the 'reduced tree canopy over invaded understorey' modified state could not be distinguished from the extent of the 'invaded mature floodplain eucalypt forests and woodlands' modified state.

Timber and firewood ecosystem service supply in the coupe is dominated by the 'invaded mature floodplain eucalypt forests and woodlands' modified state (1994.1 t) and the combination 'reduced tree canopy over invaded understorey and invaded mature floodplain eucalypt forests and woodlands' modified state (1847.1 t). This assessment also highlights that the supply of ecosystem services is dependent on the biomass characteristics of ecosystem states within the 'inland floodplain eucalypt forest and woodlands' type.

The timber removed from the 'invaded mature floodplain eucalypt forests and woodlands' state in 2015 in Gunbower Forest could drive a transition (that may be observed in later years) to the 'reduced tree canopy over invaded understorey' state. This leads to a 0.12 decline in ecosystem condition (ecological integrity), a 37% reduction in carbon stock and sequestration, and potentially a reduction in future harvest volumes for timber and firewood. This is based on the assumption that the removal of timber from the 'invaded mature floodplain eucalypt forests and woodlands' state in 2015 is greater than the capacity of this ecosystem state to provide this service, triggering a degradation event (here termed 'transition').

The state and transition model in Figure 46 also represents a likely transition from the 'reduced canopy over invaded understorey' state to the 'invaded mature floodplain eucalypt forests and woodlands' state after cessation of logging (and a timeframe of 50 to 100 years). This leads to a potential increase in carbon stock and sequestration of 277.6 tonnes and 57.4 tonnes y^{-1}, respectively across the coupe.

This example highlights the use of accounts, combined with conceptual models of ecosystems and drivers, to understand trade-offs in the supply of different ecosystem services. Further work is required to determine the amount of timber that can be harvested from different ecosystem states in the 'inland floodplain eucalypt forests and woodlands'' ecosystem type that does not result in a transition to another state (i.e. the sustainable use of ecosystem services), often termed ecosystem service potential or capacity (La notte et al. 2019a, 2019b).

9.7.3 Analysis

The quantification of ecosystem services at GKP included timber and firewood harvesting, honey production, carbon stock and sequestration, and ecosystem and species appreciation. Provision of these services is reliant on a range of ecosystem characteristics across ecosystem types. A summary of the services that flow from different ecosystem types are:

- Timber and firewood harvesting services are provided almost entirely by the 'inland floodplain eucalypt forests and woodlands' ecosystem type (across a range of modified states).
- Honey production services are also provided predominantly by the 'inland floodplain eucalypt forests and woodlands' and to a lesser extent the 're-sprouter temperate and subtropical eucalypt woodlands' ecosystem type.
- Carbon sequestration and stock services are provided by all terrestrial and wetland ecosystem types.
- Water flow regulation is provided by the 'wetlands', 'inland floodplain eucalypt forests and woodlands' and 'lowland streams' ecosystem types.

The 'inland floodplain eucalypt forests and woodlands' ecosystem type is key to supply of provisioning services for timber and firewood, honey production and global regulating services of carbon stock and sequestration. Current silviculture management regimes used in timber and firewood harvesting compartments have an impact on carbon sequestration and stock.

As discussed in Section 9.6, Gunbower and Koondrook-Perricoota forests have been exposed to quite different environmental watering regimes. Regular environmental watering of Gunbower forest has resulted in improvement to the on-ground monitoring metrics for vegetation, waterbirds and fish. While watering over the 2010 to 2015 period has not extended to the total site, areas that received environmental water have responded positively. Based on the quantitative assessment of services at Gunbower and Koondrook-Perricoota and recent environmental watering we make the following observations:

- Environmental watering of Gunbower has led to positive ecosystem responses detected from on-ground monitoring locations, although there was a slight decline in the ecosystem condition index for Gunbower Forest between 2010 and 2015. This is not surprising as conceptual models for the 'inland floodplain eucalypt forests and woodlands' (Richards et al. 2021) indicate a transition time for ecosystem states impacted by timber harvesting and reduced flooding ('reduced tree canopy over invaded understorey' modified state) of 50 to 100 years to return to reference conditions (given increases to flood duration and frequency over this time period and cessation of timber harvesting).
- The limited environmental watering at Koondrook-Perricoota over the accounting period means that there were limited resulting impacts on overall forest condition. MDBA site

monitoring indicates few ecological objectives have been met and the ecosystem condition index account shows an overall reduction in condition between 2010 and 2015 (and a lower value compared to Gunbower Forest). The continued inability to meet environmental objectives will impact the capacity of the site to provide ecosystem services into the future, such as timber and firewood harvesting, carbon sequestration, honey production and ecosystem and species appreciation.

- Extended dry periods and infrequent large-scale environmental watering is likely to reduce regeneration of the 'inland floodplain eucalypt forests and woodlands' ecosystem type, the key provider of timber services in Koondrook-Perricoota. Continued harvesting is also likely to impact ecosystem service capacity in harvest areas.
- Infrastructure works completed in 2013 at Koondrook-Perricoota provide the opportunity to increase frequency and duration of flooding at the site, which may improve ecosystem capacity and provision of services in the future, if other disturbances (invasive species, timber harvesting impacts etc.) are also managed.
- Decline in harvested wood volumes removed from Gunbower Forest over the accounting period contrast with a maintenance of timber harvesting at Koondrook-Perricoota over this same period. This change in timber harvesting disturbance regimes is likely to interact with differences in environmental watering events across the icon site to produce some of the observed changes in the on-ground site monitoring data and the ecosystem condition index. This interaction will make it difficult to ascribe changes in extent, condition and ecosystem services to a single driver.
- The combination of on-ground monitoring data used in the icon site report cards and the ecosystem condition index calculated here, could provide a useful indication of ecological trajectories along transition pathways. For example, further expert testing of the state and transition models developed for GKP could unpack the number of years where report card condition scores of level A would indicate progress along the transition trajectory from degraded states towards reference condition, while detection of a state change (improvement in the ecosystem condition index) would indicate a successful transition. In addition, given the extensive impacts of climate change across the basin, it is unlikely that GKP could return to an historical reference state and further work is required to articulate novel ecosystem states, including those that represent best possible ecosystem condition that might be achievable in the future.
- There is an opportunity to do more work on climate variability and environmental water use and its influence on supply of services. This could be achieved by supplementing the accounting work with scenario analysis. Ecosystem accounts could also be an input to more sophisticated techniques to prioritise and optimise the bundles of ecosystem services delivered from a location.

9.8 Analysis example 3 – Biodiversity

9.8.1 Background

Societies value the persistence of biodiversity ('existence value') – and Australia has enacted many state and federal laws and policies to avoid species becoming extinct. Since GKP sits within a highly modified area of Australia, the existence of many species in the region depend on GKP being maintained in good condition.

In this context, understanding how biodiversity is changing over space and time is crucial for well-informed decisions that help to retain our unique biological heritage over the long term. Tracking changes in biodiversity through environmental-economic accounting provides this information in a systematic way, including the capacity for linking to other relevant environmental and economic data for an integrated perspective.

Biodiversity is a complex concept, being the variety and variability of life, and can be considered at a range of levels, from the genetic diversity within a species all the way up to diversity between ecosystems across a region. A diverse range of species provides a greater range of ecosystem service options. Conversely, biodiversity loss directly threatens ecosystem processes and the supply of many ecosystem services across multiple scales.

Biodiversity also plays a fundamental role in maintaining the ability of ecosystem assets to supply ecosystem services in the future. The presence of a diverse range of organisms performing a given function within an ecosystem can reduce the impact of environmental changes or shocks as individual elements of this diversity are affected in different ways. This ability of an ecosystem to tolerate shocks and disturbance while maintaining the same level of functioning is often referred to as ecosystem resilience. Resilient ecosystems are more likely to supply a steady flow of ecosystems services into the future. Our best evidence at present is that maintaining diversity promotes long-term resilience and provision of ecosystem functions and services under changing environmental conditions. Biodiversity helps act as a buffer, because species are complementary in terms of their responses to perturbation and effects on ecosystem function. The asset valuation accounts assume ecosystems are resilient and are able to supply ecosystem services in perpetuity. Further work could test this assumption by forecasting changes and shocks and considering how ecosystem condition and services may respond to them in the future.

The connections between biodiversity and human activity operate in two directions. First, biodiversity can be impacted by the use of ecosystems, for example, in terms of harvesting practices for timber and fish and the extent of tourism activity. Second, choices about restoration and protection activities will have impacts on biodiversity. Decision-makers can enhance the supply of ecosystem services and increase the resilience of ecosystems with policies focused on biodiversity. Enhancing and preventing the loss of biodiversity should be considered against use and extraction from ecosystems to ensure intergenerational equity.

9.8.2 Integrated analysis of biodiversity with other accounting elements

The management of natural capital to maintain and improve ecosystem condition supports the provision of ecosystem services and the persistence of biodiversity. The ecosystem condition index account shows the condition of the ecosystems and can be used to monitor the conservation of protected areas. The MDB-wide biodiversity information provides context for GKP and enables an assessment of its relative condition and biodiversity compared to broader Basin scale.

The ecosystems of GKP provide habitat for many species, communities of species, and ecosystems. Ecosystem that are in a better condition can provide better habitat for species and they are more resilient. The habitat provides suitable physical and biological conditions for recruitment, pollination, reproduction and food sources supporting the life cycle. These species and communities are an important attribute that are valued by people. Both recreational services and species appreciation rely on good ecosystem condition and biodiversity.

Figure 48 shows integrated view of changes in ecosystem extent, condition, biodiversity and ecosystem services between 2010 and 2015. Additional analysis is required to explore causal links.

Table 64 shows a combined presentation of extent, condition, biodiversity and recreation services. Additional analysis is required to explore causal links. Note that the recreation survey included results showing how respondents would change number of visit days if fish, waterbirds and native vegetation changed, some of which can be related to the condition and biodiversity accounts presented in this report.

Figure 48 Percent change for extent, condition, biodiversity, services and value, from 2010 to 2015

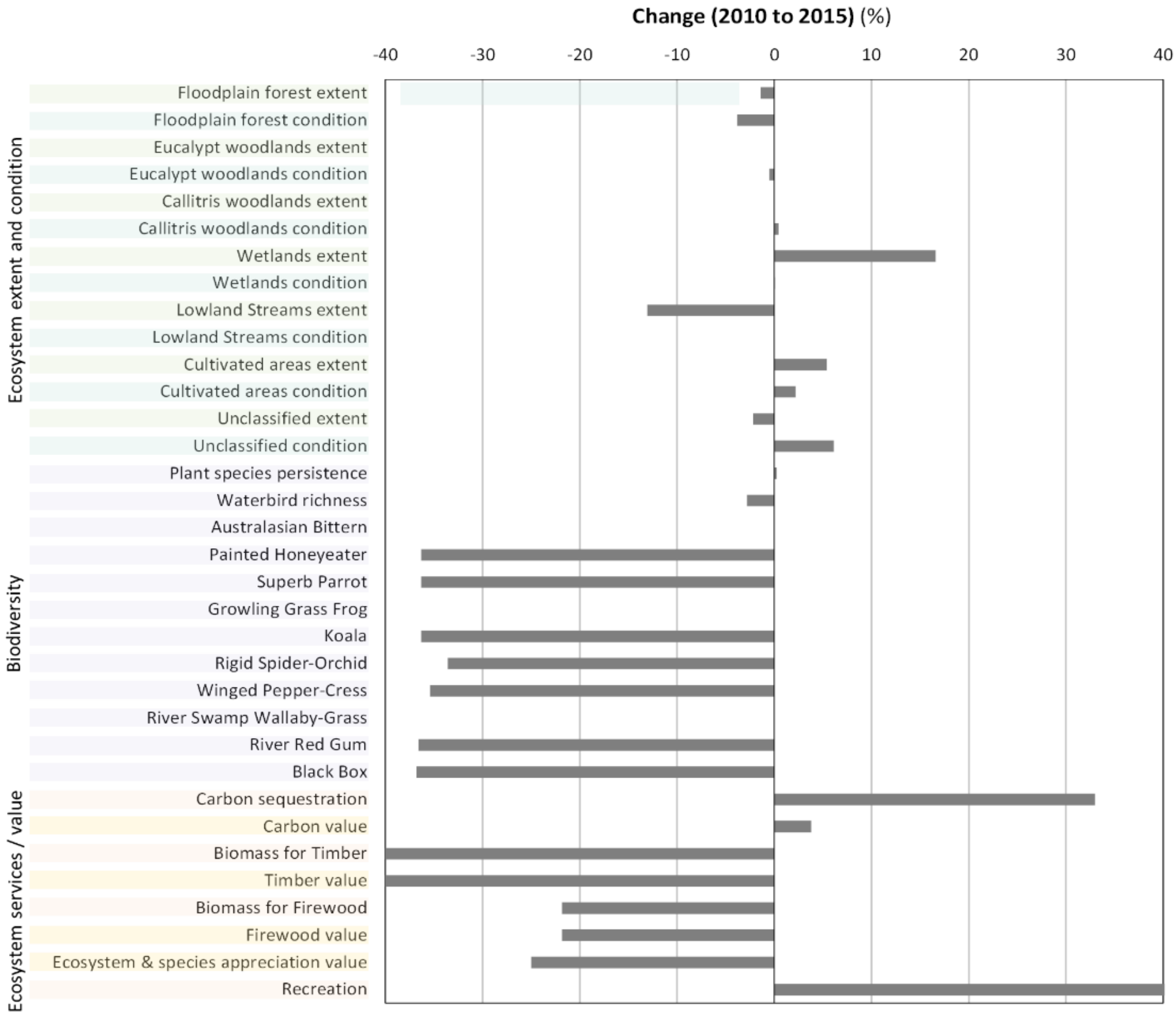


Table 64 Combined presentation: extent, condition, biodiversity and recreation services for GKP

Ecosystem type	Ecosystem state	Extent (ha)		Ecosystem condition index		Average number of waterbird species		Expected species persistence (%) for vascular plants		Recreation services: visit days	
		2010	2015	2010	2015	2010	2015	2010	2015	2010	2015
Inland floodplain eucalypt forests and woodlands	Reference	1,288	6	0.860	0.687	17.12	15.55	85.0	85.3		
	Modified: Reduced tree canopy over invaded understorey	13,694	12,983	0.457	0.455	16.26	15.94	84.9	85.0		
	Modified: Invaded mature floodplain eucalypt forests and woodlands	4,698	6,920	0.596	0.584	19.23	17.72	84.8	85.1		
	Modified: Invaded mature floodplain eucalypt forests and woodlands or Reduced tree canopy over invaded understorey*	26,005	23,728	0.503	0.500	16.66	16.21	85.0	85.1		
	Modified: Halophytic state	1,469	2,843	0.160	0.160	16.48	16.25	85.0	85.2		
Re-sprouter temperate and subtropical eucalypt woodlands	Reference	–	–	Na	Na	Na	Na	Na	Na		
	Modified: Grey box woodlands with exotic understorey	1,854	1,854	0.612	0.609	18.76	18.44	84.6	84.8	211,000	340,000
Fire-intolerant *Callitris* woodlands	Reference	–	–	Na	Na	Na	Na	Na	Na		
	Modified: Low-rise sandhill pine woodlands	36	36	0.470	0.481	19.98	18.71	85.1	85.2		
	Modified: High-rise sandhill pine woodlands	421	421	0.170	0.170	16.99	16.38	84.8	85.0		
Wetlands	Reference	–	–	Na	Na	Na	Na	Na	Na		
	Modified: High-condition wetlands	34	34	0.794	0.779	19.68	17.59	84.0	84.1		
	Modified: Moderate-condition wetlands *or* Low-condition wetlands†	4,841	5,650	0.469	0.469	17.24	16.26	85.0	85.2		
Lowland streams	Reference	–	–	Na	Na	Na	Na	Na	Na		

Ecosystem type	Ecosystem state	Extent (ha)		Ecosystem condition index		Average number of waterbird species		Expected species persistence (%) for vascular plants		Recreation services: visit days	
		2010	2015	2010	2015	2010	2015	2010	2015	2010	2015
	Modified: Managed flows	1,125	978	0.583	0.583	23.68	24.03	84.2	84.3		
Cultivated areas	Cultivated areas	334	352	0.303	0.309	14.92	14.94	84.8	85.0		
Unclassified	Unclassified	226	221	0.529	0.562	16.96	17.20	85.0	85.2		

Note '–' = 0, Na = not applicable

*In this area, the extent of the 'reduced tree canopy over invaded understorey' modified state could not be distinguished from the extent of the 'invaded mature floodplain eucalypt forests and woodlands' modified state.

†The extent of the 'moderate-condition wetlands' modified state could not be distinguished from the extent of the 'low-condition wetlands' modified state.

Source: Richards et al. (2021a, 2021b), Mokany et al. (2021a, 2021b), Cheesman et al. (2021)

10 Key findings

The key findings from this project relate to the biophysical and economic results presented in the accounts, as well as the methods and approach used for ecosystem accounting. It is clear from the project that there are opportunities to improve and extend the methods and data so that accounting-based information can be used to more effectively support decision making. A range of next steps and priority actions are recommended for coordination, GKP accounts and other accounts.

10.1 Results from the GKP accounts

- Six ecosystem types occurred in GKP in 2010 and 2015:
    - inland floodplain eucalypt woodlands and forests
    - re-sprouter temperate and subtropical eucalypt woodlands
    - fire-intolerant *Callitris* woodlands
    - wetlands
    - lowland streams
    - cultivated areas.
- Across both 2010 and 2015, 11 ecosystem states represented by 26 ecosystem expressions at GKP were identified within these ecosystem types. All but 223 ha could be classified in an ecosystem state and ecosystem expression.
- 'Inland floodplain eucalypt forests and woodlands' was the dominant ecosystem type in 2010 and 2015, making up approximately 85% of the total area of GKP in both years. Wetlands were the second most dominant with a share of approximately 10% in both years.
- Between 2010 and 2015, the largest changes in extent were in:
    - inland floodplain eucalypt forests and woodlands (net decrease of 675 ha relative to 2010, about 1.5% of the 2015 extent)
    - wetlands (net increase of 808 ha relative to 2010, about 14% of the 2015 extent).
- The ecosystem condition index shows GKP, in general, to be in moderate condition, with aggregated mean scores of 0.498 and 0.481 for 2010 and 2015, respectively, on a scale from 0.0 (ecosystem completely removed) to 1.0 (ecosystem in reference condition).
- The largest changes in condition were observed in the 'inland eucalypt floodplain forests and woodlands' ecosystem type and 'cultivated areas'.
    - These small changes in ecosystem condition are unsurprising given ecological timeframes are long, and major changes in condition are not expected to manifest over a 5-year time frame.
- While 5 years is relatively brief in terms of biodiversity dynamics, the methods applied here detected small changes over the reporting period. For GKP, from 2010 to 2015:
    - the expected persistence of vascular plants increased slightly (from 84.9% to 85.1% of species expected to persist over the long term)
    - mean local species richness of waterbirds decreased slightly (from 17.0 to 16.6 species)

- the estimated area of suitable habitat for the focal species either remained steady (for 3 of the 10 species) or decreased (for 7 of the 10 species).

- Reductions in diversity for waterbirds and habitat for most focal species from 2010 to 2015 in GKP are likely related to dramatic differences in water availability between these 2 years.
- Comparing the state jurisdictions within GKP, Victoria performed slightly better for waterbirds and the focal species.
- 47,988 total tonnes of biomass for timber were harvested across the GKP in 2010, dropping to 9,027 tonnes of total yield in 2015. Biomass for timber was only harvested from the 'inland floodplain eucalypt forests and woodlands' ecosystem type.
- Timber harvested in 2010 had a total monetary value of around $868,000. Of this total, $66,000 was supplied by the Gunbower Forest and $802,000 by the Koondrook-Perricoota Forest.
- In 2010 and 2015, the total firewood yield across GKP was 74,131 tonnes and 57,937 tonnes, respectively. All firewood was harvested from the 'inland floodplain eucalypt forests and woodlands' ecosystem type and is allocated to the local firewood industry.
- Total biomass for firewood harvested in 2010 has a residual rent of around $1,482,000. The total residual rent of harvest from GKP in 2015 is around $1,159,000.
- The total supply of carbon sequestration services was 1,022,807 tonnes in 2010 and 1,030,771 tonnes in 2015.
- The 2010 total monetary supply and use of carbon sequestration relying on exchange values from the World Bank Carbon Pricing Dashboard was around $71 million. Inland floodplain eucalypt forests and woodlands supplied around $25.1 million and $42.2 million of monetary supply and use across Gunbower Forest and Koondrook-Perricoota Forest respectively.
- The 2015 total monetary supply and use of carbon sequestration relying on ACCU exchange values from the World Bank Carbon Pricing Dashboard was around $94 million. Inland floodplain eucalypt forests and woodlands supplied around $35.6 million and $53.6 million of monetary supply and use across Gunbower Forest and Koondrook-Perricoota Forest respectively.
- There was a total of 44,812 and 28,597 ha of habitat suitable for 8 focal species in 2010 and 2015 respectively.
- Ecosystem and species appreciation in 2010 had a total exchange value of around $150 million. The 'inland floodplain eucalypt forests and woodland' ecosystem type provides the largest proportion of value in both 2010 and 2015. In 2010, this ecosystem type provided around $46.5 million of exchange value from Gunbower and around $71.2 million from the Koondrook-Perricoota.
- In 2015, the total ecosystem and species appreciation exchange value fell slightly to around $113 million. In 2015, the 'inland floodplain eucalypt forests and woodlands' ecosystem type provided around $30.4 million of exchange value from the Gunbower and around $45.2 million from the Koondrook-Perricoota.

- In 2010, total visit days to Gunbower and Koondrook-Perricoota are estimated at 211,000. In 2015, total visit days to Gunbower and Koondrook-Perricoota are estimated at 340,000. Around three-quarters of total visit days are in Gunbower National Park.
- In 2010, consumption expenditure attributable to Gunbower and Koondrook-Perricoota is estimated at $14.3 million. In 2015, consumption expenditure attributable to Gunbower and Koondrook-Perricoota is estimated at $21.7 million. Around 72% of total consumption expenditure is again attributable to Gunbower National Park.

10.2 Methods and data for ecosystem accounting

This case study built on existing methods for ecosystem accounting and biodiversity accounting but also introduced novel approaches to accounting for ecosystem extent, condition and services using dynamic conceptual models (Richards et al. 2021c). Scientists, economists and accounting experts built on decades of international work to further develop accounting methods that tailor, extend and more strongly couple existing techniques. Key aspects of the approach and important advances included the use of:

- The Australian Ecosystem Models Framework (Richards et al. 2020), a national framework of dynamic models of ecosystems that describe ecosystem states and reference conditions.
- The Habitat Condition Assessment System (Williams et al. 2021), which has provided Australia with its first consistent, repeatable and national assessment of ecosystem condition.
- Biogeographic modelling Infrastructure for Large-scale Biodiversity Indicators (BILBI), which uses best-available biological and environmental data, modelling and high-performance computing to assess biodiversity change at fine spatial resolution across the global land surface.
- Quantification of ecosystem services were assessed within a consistent conceptual framework that defined spatial areas of service supply, biophysical characteristics of service provision, current management regimes and service quantification (modelling and biophysical calculations).
- Global carbon stock and sequestration for terrestrial vegetation was modelled adapting GKP vegetation attributes from expert elicitation. Wetland carbon stock and sequestration were estimated based on wetland types assessed by Carnell et al (2018) aligned with relevant ecosystem states and expressions for GKP wetlands.
- Pollination and floral resources for honey production were based on consultation with the apiary industry. Apiary industry experts provided the most explicit knowledge of flowering responses to climate variability, timing and indicators of long-term planning.
- Ecosystem services valuation approach for carbon sequestration was based on methods established by DEWLP in their scoping report for Urban Ecosystem Accounts for Melbourne (2021).

The methods are based on coherent concepts and align with the SEEA EA framework, and demonstrate how to:

- use reference states and reference condition when determining ecosystem type
- distinguish between natural variability and human-made changes

- develop ecosystem classifications and conceptual models that reflect Australia's unique ecology
- link ecosystem condition characteristics across all relevant components of ecosystem accounts (extent, condition, services and benefits).

The data was generally of high quality and coherent (Figure 49). Data were sourced from:

- experts' understanding of ecosystem dynamics, as documented in the dynamic conceptual models (Richards et al. 2021c)
- continental-scale remotely sensed data
- regionally produced spatial datasets, maps and models
- targeted field surveys and expert-elicited data in 2020.

Table 65 summarises the confidence in the GKP ecosystem accounts presented in this report, along with limitations and opportunities for improvement.

Table 65 Overview of limitations and opportunities for GKP accounts

Concept	Accounts	Confidence	Limitation	Opportunity for improvement
Ecosystem extent	Ecosystem extent	Medium	No detection of understorey composition using remote sensing data, which is needed to differentiate exotic from native understorey. Mismatch between time period and some remotely sensed data. Inundation frequency and duration derived from modelled data.	Additional on-ground validation data (especially for wetlands and lowland streams). Detailed sensitivity analysis of mapping workflow.

Concept	Accounts	Confidence	Limitation	Opportunity for improvement
Ecosystem condition	Ecosystem condition variable Ecosystem condition index	Medium	Expert elicitation of condition scores was a pilot. Mismatch in spatial grid resolution of HCAS and extent datasets. Imperfect separation of managed and unmanaged disturbances in ecosystem condition. Ecosystem condition assessed using two 10-year epochs that overlap the change period due to limited remote sensing time series.	Assess auxiliary information to verify change detection. Undertake further expert elicitation to validate reference sites used, and generate more locally applicable validation and calibration data, implemented with statistical cross-calibration between experts. Quantify whole-model uncertainty to provide site-level confidence intervals. Blend remote sensing imagery nationally to extend the spatial resolution of HCAS from 250 m to 90 m or 100 m nationally. Develop methods for annual or even more frequent assessment of ecosystem condition, and/or custom products for relevant services.
Ecosystem services and benefits	Biomass for timber and firewood	Medium – Coupes spatially defined Low –Timber ecosystem state	Details of expected yield in each coupe, limited detail of area actually harvested Gunbower qualitative yield estimate no actual data available	Obtain detailed harvest plans, area harvested each year and production statistics
	Floral resources for honey	Medium – licence areas known. Potential utilisation of licences not known	No honey production 2010 and 2015 to test accuracy KP licence areas difficult to quantify use	Survey apiarists to improve areas of highest yield
	Carbon sequestration and stock	Medium	Not all aspects of model updated with GKP vegetation characteristics. Wetland stock and sequestration estimates based on limited data	vegetation characteristics detailed as FullCAM input Wetland estimates
	Floral resources for hive building	Medium	Time series lack significant flowering events. Primary knowledge with apiarists	Monitoring of flowering events and key drivers at GKP and alignment with natural and environmental watering events

Concept	Accounts	Confidence	Limitation	Opportunity for improvement
	Ecosystem and species appreciation	Low		
	Water flow regulation	Low	Use of counter factual approach requires modelling to determine inundation as >1% event	Hydraulic modelling to cover River Murray channel and Thule and Barbers Ck for counter factual analysis
	Recreation Recreation activities	High – survey data is high quality	Not directly attributable to GKP Local visitation not included in estimates (except recreational fishing)	Survey visitors – distinguish between local, domestic, and international visitors in boat ramp surveys.
Biodiversity	Community-level: vascular plants	High	Based on habitat condition that uses the preceding 10 years of data	Develop a new method for annual or even more frequent assessment of habitat condition
	Community-level: waterbirds	Medium	Does not consider landscape context nor full implications of habitat change for long-term persistence	Apply more sophisticated techniques as for vascular plants Could attribute the benefits for waterbird diversity of past or future environmental watering actions, through linking observed surface water coverage with that predicted using hydrological models under past or future scenarios.
	Species-level: 10 focal species	Medium	Does not consider landscape context nor full implications of habitat change for long-term persistence Difficult to detect semi-aquatic vegetated habitats of some species by land cover mapping. Only 10 species assessed - not taxonomically nor spatially representative of 500,000 species in Australia	Apply more sophisticated techniques as for vascular plants Further refinement of the spatial land cover products and species habitat requirements Potential extent of occurrence for each species could be refined to enable estimates of total changes in habitat remaining relative to the estimated area of original habitat (a firmer benchmark) Harness other research aiming to map changes in the availability of suitable habitat for specific iconic species, such as the koala (Rhodes 2020) Consider a more advanced process for selecting a suitably broad, representative and meaningful set of species

Concept	Accounts	Confidence	Limitation	Opportunity for improvement
All			Data available only for calendar years (for example, land cover, WOfS)	Resample data for financial year to better match economic data and MDBA's water management periods
Ecosystem classification and conceptual models		Medium	First Nations Australians knowledge and perspectives not included in conceptual models. Only past and current states identifed - not future novel states.	Work with First Nations Australians to identify whether or how Indigenous ecological knowledge may be woven or developed into parallel conceptual models via Indigenous-led expert elicitation Develop expert-informed novel states, underpinned by future land use and climate scenarios, to estimate future flows of ecosystem services and capacity

10.3 Conclusion

This project delivered a series of ecosystem accounts, covering ecosystem extent and condition, biodiversity, the flow of a set of ecosystem services and the benefits or value (monetary and non-monetary) these services provide.

This case study built on existing methods for ecosystem accounting and biodiversity accounting but also introduced novel approaches to accounting for ecosystem extent, condition and services using dynamic conceptual models. Scientists, economists and accounting experts built on decades of international work to further develop accounting methods that tailor, extend and more strongly couple existing techniques, and align with the SEEA EA framework.

The study provides insights into how future ecosystem accounts could be developed for other sites, the Murray-Darling Basin and Australia.

10.3.1 Quality declaration

The accounts in this document reflect the concepts and definitions of the United Nations System of Environmental-Economic Accounting. In addition, to respond to the policy and analytical requirements of this project some complementary monetary values have been included that go beyond the scope of monetary valuation based on exchange values in the SEEA EA. Specifically, non-use values relating to ecosystem and species appreciation have been estimated and, for timber provisioning, recreation and the carbon sequestration component of global climate regulation services, welfare values have been derived.

Non-use values are excluded from the scope of the SEEA EA because they are not associated with a transaction between an ecosystem and people that is required for treatment as an ecosystem service in the SEEA EA. Welfare values differ from exchange values in large part because the former include measures of consumer surplus which the latter do not.

Further, while conceptually aligned with the SEEA EA, the approach used for measuring condition differs from the three-stage approach described in the SEEA EA Chapter 5. While stage 1 and stage 3 condition accounts are presented, we did not derive values for individual characteristics relative to reference levels (stage 2). In the future, when methods and data are further advanced it would be expected that the estimates in this report would also change.The accounts in this document reflect the concepts and definitions of the United Nations System of Environmental-Economic Accounting. In addition, non-use values, which are excluded from monetary valuation in the SEEA, have been included in this report to respond to the policy and analytical requirements of this project. Also, for some ecosystem services welfare values have been derived to complement the exchange values used in the accounts. Further, while conceptually aligned with the SEEA EA, the approach used for measuring condition differs from the three-stage approach described in the SEEA EA Chapter 5 in not deriving values for individual characteristics relative to reference levels (stage 2). In the future, when methods and data are further advanced it would be expected that the estimates in this report would also change.

Consistency with Action Plan

This work is part of the strategy on the implementation of the SEEA in Australia as articulated in Environmental Economic Accounting: A Common National Approach Strategy and Action Plan. The Strategy and Action Plan provides the basis for Commonwealth, state and territory governments to advance the use of EEA through a common national approach and will build on existing efforts by:

- adopting the United Nations System of Environmental-Economic Accounting throughout Australia
- producing a core set of national environmental-economic accounts to inform decision-making in government, community and business.

The first five years of implementation of the strategy and action plan focus on:

- improving the availability of account-ready data
- development of experimental national scale accounts

- identifying priority environmental-economic information needs
- improving consistency in EEA at all scales
- capacity building in multiple sectors to help decision-makers understand the uses and value of EEA.

The GKP project is one of several pilot projects that are being applied simultaneously to test the methods, classifications and data compilation approaches that will be integral to informing the national approach.

11 Appendix

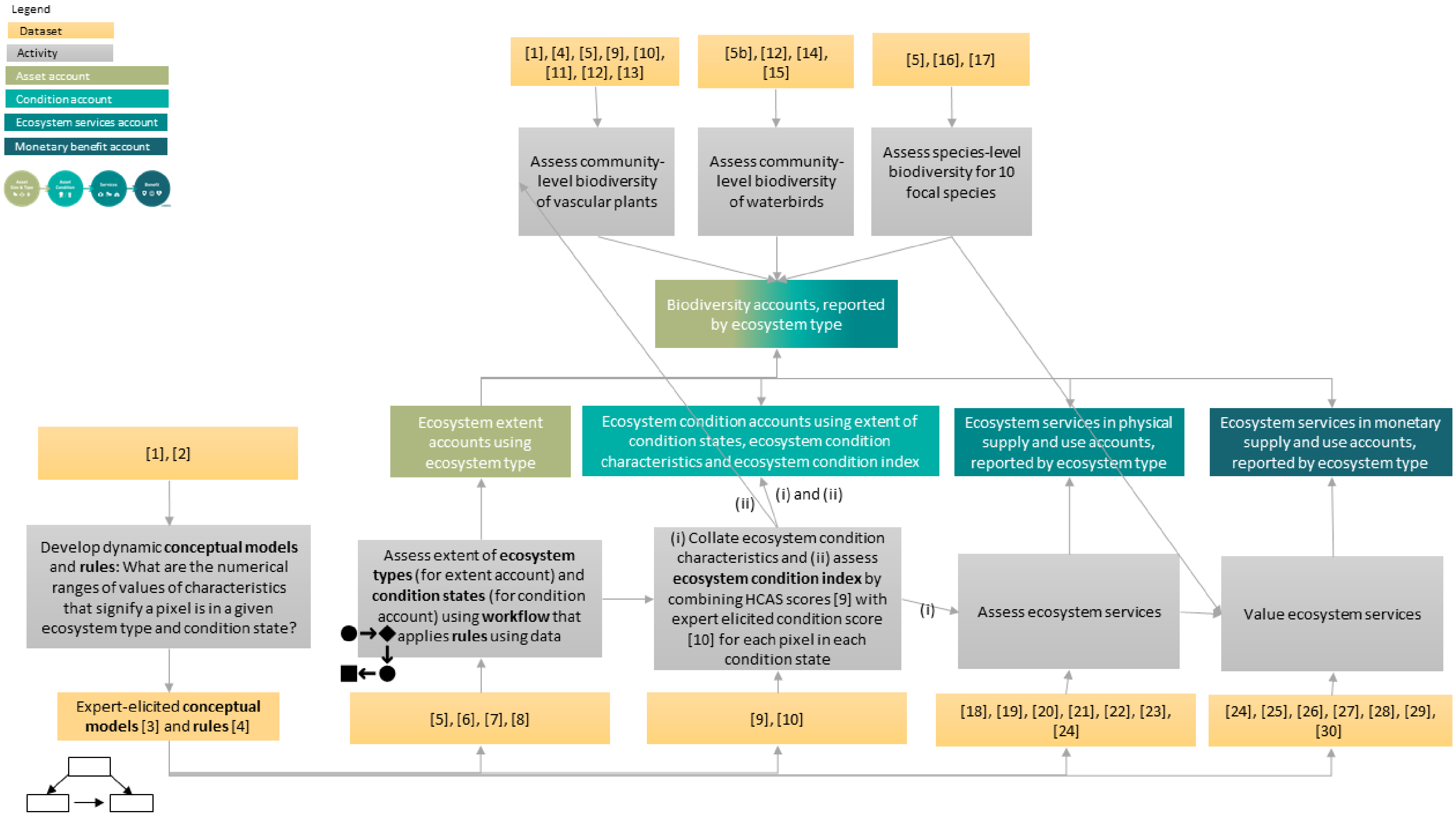
This appendix provides additional information:

- the workflow for developing account-ready data (Figure 49)
- ecosystem extent accounts by expression (Table 66 to Table 70) (note these are not provided for the cultivated ecosystem type and the unclassified areas, as no expressions were defined for these)

stage 1 ecosystem condition variable accounts (Table 71 to

- Table 77).

Figure 49 Workflow for developing account-ready data, including input datasets and dependencies across activities



[1] Richards et al. (2020)
[2] Existing information about vegetation types at GKP:

- maps of 1750 EVC (EVC benchmarks – Murray Fans bioregion) for Gunbower Forest (DSE 2004)
- water regime classes of Gunbower Forest (Cooling et al. 2002)
- maps of plant community types (Bionet vegetation classification, NSW – Murray and Riverine region) for Koondrook-Perricoota Forest (Benson 2006; OEH 2018)
- maps of National Vegetation Information System major vegetation sub-groups, version 5.1 (ESCAVI 2003)
- supplementary information from Overton et al. (2014), MDBC (2006) and Hale and Butcher (2011).

[3] Expert-elicited conceptual models as described in Richards et al. (2021b)
[4] Rules in the dataset (Prober et al. 2021).
[5] Both the land classes and the raw data came from the land cover dataset (GA 2020), which was developed using Digital Earth Australia and the Land Cover Classification System. See Appendix B in Richards et al. (2021b). The raw data from the land cover dataset comprise the following Essential Environmental Descriptors:

- Fractional cover (FC)
- Water Observations from Space (WOfS) (Mueller et al. 2016)
- Intertidal Extents Model (ITEM)
- National mangrove extent
- Machine learning applied to annual geometric medians (geomedians) and median absolute deviations (MADs)
- Machine learning applied to Landsat time series
- Woody cover fraction (WCF)
- Tasselled cap wetness (TCW)

[6] Other continental-scale remotely sensed data. See Appendix B in Richards et al. (2021b). These are the Additional Environmental Descriptors:

- Vegetation above-ground biomass (AGB)
- Global forest canopy height

[7] Regionally produced spatial datasets, maps and models - see Appendix C in Richards et al. (2021b). These include:

- River Murray Flow Inundation Model (RiMFIM) for inundation, duration and consecutive duration of inundation (Chen et al. 2012; Overton et al. 2006)
- Interim Australian National Aquatic Ecosystem (ANAE) classification (Group AET 2012)
- 1750 and 2005 EVC (EVC benchmarks – Murray Fans bioregion) for Gunbower Forest (DSE 2004) and updated EVC mapping in the upper section of Gunbower Forest (Bennetts 2014)
- Water Regime Classes (WRC) for Gunbower Forest and Koondrook-Perricoota Forest (Cooling et al. 2002)
- Plant community types (Bionet vegetation classification, NSW – Murray and Riverine region) for Koondrook-Perricoota Forest (Benson 2006; OEH 2018)
- Murray-Darling Basin vegetation tree (MDBVT) map produced by Cunningham et al. (2013) that is a tree classification layer for red gum, black box and coolabah species developed from state-based vegetation survey data.
- Murray-Darling Basin tree stand condition assessment tool (Newell et al. 2017) is a predictive model of stand condition (canopy health) in river red gum, black box and coolabah forests and woodlands in the Murray-Darling Basin between 2009 and 2016.

[8] On-ground datasets – see Appendix D in Richards et al. (2021b)

- long-term monitoring plots managed under the TLM program by the North Central Catchment Management Authority and Forestry NSW (Bennetts 2014; Bennetts and Jolly 2017; Forbes and Wills 2016, 2017)
- 25 additional on-ground data points collected at GKP in 2020

[9] published HCAS v2.1 dataset (Williams et al. 2021)
[10] Expert-elicited condition scores, Apx Table D.1 in Harwood et al. (2021a)
[11] 66,608 survey plots (including MDBA data) (Mokany et al. 2021a)
[12] Spatial environment data (Mokany et al. 2021a)
[13] Biodiversity models for vascular plants (Mokany et al. 2021a)
[14] >2 million records (95 species) (including MDBA surveys) (Mokany et al. 2021a)
[15] Biodiversity models for waterbirds (Mokany et al. 2021a)
[16] Species habitat requirements (DAWE 2020a)
[17] Species of National Environmental Significance Distributions - public grids (DAWE 2020b)
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[22] Extent and condition data for ecosystem states (Richards et al. 2021a) and biodiversity persistence (Mokany et al. 2021a)
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Table 66 Ecosystem extent account, by ecosystem expression, 'inland floodplain eucalypt forests and woodlands' ecosystem type, 2010 to 2015

Extent (ha)										
Ecosystem type	Inland floodplain eucalypt forests and woodlands								Re-sprouter temperate and subtropical eucalypt woodlands	Total
	Reference		Modified						Modified	
Ecosystem state	Reference		Reduced tree canopy			Invaded mature	Reduced tree canopy *or* Invaded mature*	Halophytic state	Grey box woodlands	
Ecosystem expression	Mature floodplain	Dense seedling eucalypts	Dense seedling eucalypts invaded	Reduced tree canopy invaded	Dense pole eucalypt	Invaded mature floodplain	Reduced tree canopy invaded *or* Invaded mature floodplain†	Invaded halophytic shrubland	Grassy woodlands with exotic understorey	
Opening extent	1,287	2	1	11,911	1,783	4,698	26,005	1,469	–	47,154
Additions to extent										
Managed expansion	–	5	5	2,328	51	3,453	2,597	2,518	–	10,956
Unmanaged expansion	–	–	–	–	–	–	–	–	–	–
Unclassified expansion	–	–	–	–	–	–	–	–	–	–
Total expansions	–	5	5	2,328	51	3,453	2,597	2,518	–	10,956
Reductions in extent										
Managed reduction	1,286	1	–	2,472	687	1,368	4,936	1,148	–	11,899
Unmanaged reduction	–	–	–	–	–	–	–	–	–	–

Extent (ha)	Ecosystem type	Inland floodplain eucalypt forests and woodlands								Re-sprouter temperate and subtropical eucalypt woodlands	Total
	Ecosystem state	Reference		Modified						Modified	
		Reference		Reduced tree canopy			Invaded mature	Reduced tree canopy *or* Invaded mature*	Halophytic state	Grey box woodlands	
	Ecosystem expression	Mature floodplain	Dense seedling eucalypts	Dense seedling eucalypts invaded	Reduced tree canopy invaded	Dense pole eucalypt	Invaded mature floodplain	Reduced tree canopy invaded *or* Invaded mature floodplain†	Invaded halophytic shrubland	Grassy woodlands with exotic understorey	
Unclassified reduction		–	–	–	–	–	–	–	–	–	–
Total reductions		1,286	1	–	2,472	687	1,368	4,936	1,148	–	11,899
Net change in extent		–1,286	3	5	–144	–636	2,085	–2,339	1,370	–	–943
Closing extent (2015)		–	5	5	11,767	1,147	6,783	23,666	2,838	–	46,212

Note: Mature floodplain = Mature floodplain eucalypt forests and woodlands, Dense seedling eucalypts = Dense seedling eucalypts, Dense seedling eucalypts invaded = Dense seedling eucalypts with invaded understorey, Invaded mature floodplain = Invaded mature floodplain eucalypt forests and woodlands, Invaded halophytic shrubland = Invaded halophytic shrubland, grassy woodlands with exotic understorey = Grey box grassy woodlands with exotic understorey, '–' = 0

*In this area, the extent of the 'reduced tree canopy over invaded understorey' modified state could not be distinguished from the extent of the 'invaded mature floodplain eucalypt forests and woodlands' modified state.

†In this area, the extent of the 'reduced tree canopy over invaded understorey' expression could not be distinguished from the extent of the 'invaded mature floodplain eucalypt forests and woodlands' expression.

Source: Richards et al. (2021a, 2021b)

Table 67 Ecosystem extent account, by ecosystem expression, 're-sprouter temperate and subtropical eucalypt woodlands' ecosystem type, 2010 to 2015

Extent (ha)			Total
	Ecosystem type	Re-sprouter temperate and subtropical eucalypt woodlands	
	Ecosystem state	Modified	
		Grey box woodlands	
	Ecosystem expression	Grey box grassy woodlands with exotic understorey	
Opening extent		1,854	1,854
Additions to extent			
Managed expansion		–	–
Unmanaged expansion		–	–
Unclassified expansion		–	–
Total expansions		–	–
Reductions in extent			
Managed reduction		–	–
Unmanaged reduction		–	–
Unclassified reduction		–	–
Total reductions		–	–
Net change in extent		–	–
Closing extent (2015)		1,854	1,854

Note: The grey box grassy woodlands with exotic understorey state is made up of two expressions that could not be distinguished '–' = 0
Source: Richards et al. (2021a, 2021b)

Table 68 Ecosystem extent account, by ecosystem expression, 'fire-intolerant *Callitris* woodlands' ecosystem type, 2010 to 2015

Extent (ha)	Ecosystem type	Fire-intolerant *Callitris* woodlands		Total
	Ecosystem state	Modified		
		Low-rise sandhill pine	High-rise sandhill pine	
	Ecosystem expression	Senescent *Allocasuarina* over invaded understorey	Denuded canopy	
Opening extent		36	421	457
Additions to extent				
Managed expansion		–	–	–
Unmanaged expansion		–	–	–
Unclassified expansion		–	–	–
Total expansions		–	–	–
Reductions in extent				
Managed reduction		–	–	–
Unmanaged reduction		–	–	–
Unclassified reduction		–	–	–
Total reductions		–	–	–
Net change in extent		–	–	–
Closing extent (2015)		36	421	457

Note: Senescent *Allocasuarina* over invaded understorey = Senescent *Allocasuarina* over invaded understorey, Denuded canopy = Denuded canopy and no understorey strata, '–' = 0
Source: Richards et al. (2021a, 2021b)

Table 69 Ecosystem extent account, by ecosystem expression, 'wetlands' ecosystem type, 2010 to 2015

Extent (ha)	Ecosystem type	Wetlands						Total
	Ecosystem state	Modified						
		High-condition wetlands	Moderate- *or* low- condition wetlands†					
	Ecosystem expression	High-condition wetlands*	Permanent wet	Semi-permanent wet	Temporary wet	Mudflat‡	Dirt	
Opening extent		34	254	428	4,159		1	4,875
Additions to extent								
Managed expansion		–	–	–	–	–	–	–
Unmanaged expansion		–	1	1	5	–	3	9
Unclassified expansion		–	–	–	–	–	–	–
Total expansions		–	1	1	5	–	3	9
Reductions in extent								
Managed reduction		–	27	115	38	–	–	180
Unmanaged reduction		–	1	5	3	–	–	9
Unclassified reduction		–	–	–	–	–	–	–
Total reductions		–	28	120	41	–	1	189
Net change in extent		–	-28	-119	-36	–	3	-180
Closing extent (2015)		34	226	309	4,122	–	4	4,695

Note: High-condition wetlands = High-condition wetlands, Dirt = Dirt, Permanent wet = Permanent wet (moderate or low condition), Semi-permanent wet = Semi-permanent wet (moderate or low condition), Temporary wet = Temporary wet (moderate or low condition), Mudflat = Mudflat (moderate condition).

*'High-condition wetlands' expression is an aggregation of all high-condition wetland expressions.

†In this area, the extent of the 'moderate-condition wetlands' modified state could not be distinguished from the extent of the 'low-condition wetlands' modified state.

‡No mudflat expressions were observed in 2010. Mudflat contained 0.25ha in 2015 which rounds down to '0'.

'–' = 0

Source: Richards et al. (2021a, 2021b)

Table 70 Ecosystem extent account, by ecosystem expression, 'lowland streams' ecosystem type, 2010 to 2015

Extent (ha)	Ecosystem type	Lowland streams	Total
	Ecosystem state	Modified	
		Managed flows	
	Ecosystem expression	River Murray main channel *or* Irrigation supply channel*	
Opening extent		1,125	1,125
Additions to extent			
Managed expansion		–	–
Unmanaged expansion		–	–
Unclassified expansion		–	–
Total expansions		–	–
Reductions in extent			
Managed reduction		204	204
Unmanaged reduction		–	–
Unclassified reduction		–	–
Total reductions		204	204
Net change in extent		-204	-204
Closing extent (2015)		921	921

*The extent of the 'River Murray main channel' expression and the 'irrigation supply channel' expression is reported in combination.

'–' = 0

Source: Richards et al. (2021a, 2021b)

Table 71 Ecosystem condition variable account, 'inland floodplain eucalypt forests and woodland' ecosystem type

Type	**State**	**Reference ('Inland floodplain eucalypt forests and woodlands' ecosystem type)**					
	Expression	**Mature floodplain eucalypt forests and woodlands**		**Dense seedling eucalypts**		**Areal weighted average for the state**	
	Year	**2010**	**2015**	**2010**	**2015**	**2010**	**2015**
Physical and chemical	Water persistence (months)	5	NA	5	5	5	5
Structural	Aboveground live biomass (t/ha)	226	NA	4	4	226	4
	Aboveground standing dead biomass (t/ha)	52	NA	ND	ND	Na	Na
	Average stem diameter (m)	–	NA	ND	ND	Na	Na
	Canopy cover	NC	NC	NC	NC	53	37
	Canopy cover of second layer (%)	3	NA	–	–	3	–
	Canopy cover of third layer (%)	50	NA	–	–	50	–
	Canopy cover of upper layer (%)	40	NA	20	20	40	20
	Cover of organic litter (%)	53	NA	ND	ND	Na	Na
	Height of second layer (m)	5	NA	–	–	5	–
	Height of third layer (m)	2	NA	–	–	2	–
	Height of upper layer (m)	27	NA	2	2	27	2
	Live basal area (m2/ha)	10	NA	ND	ND	Na	Na
	Live basal area index	NC	NC	NC	NC	4	3
	Number of large trees (ha-1)	15	NA	–	–	15	–
	Number of structural layers	3	NA	1	1	3	1
	Stand condition score	4	NA	ND	ND	Na	Na
	Stand condition index	NC	NC	NC	NC	5	3
	Stem density (stems/ha)	72	NA	ND	ND	Na	Na
	Total basal area (m2/ha)	11	NA	ND	ND	Na	Na
Composition	Cover of exotic plant species (%)	3	NA	–	–	3	–

Type	State	Reference ('Inland floodplain eucalypt forests and woodlands' ecosystem type)					
	Expression	**Mature floodplain eucalypt forests and woodlands**		**Dense seedling eucalypts**		**Areal weighted average for the state**	
	Year	**2010**	**2015**	**2010**	**2015**	**2010**	**2015**
	Cover of native plant species (%)	27	NA	ND	ND	Na	Na
	Richness of exotic understorey plant species 100m-2	6	NA	–	–	6	–
	Richness of native understorey plant species 100m-2	10	NA	ND	ND	Na	Na
	Woodland bird species richness	92	NA	ND	ND	Na	Na
	Woody cover fraction	NC	NC	NC	NC	–	–
Functional	mean number of months inundated	NC	NC	NC	NC	–	–
	percentage of years inundated (%)	NC	NC	NC	NC	5	–

Note: NA = No area, NC = Not calculated because data is spatially continuous and does not need to be summarised by expression before aggregation, ND = No data, Na = not applicable. Areal weighted average is an area weighted average of the expressions in the state. The areal weighted average is Na if there is a no data value or not applicable value in the row. Woody cover fraction units is proportion of woody plant material. Where there is one expression inside a state, the areal weighted average is equal to the values in the expression. '–' = 0
Source: Harwood et al. (2021a), Prober et al. (2021)

Table 72 Ecosystem condition variable account, 'inland floodplain eucalypt forests and woodland' ecosystem type

Type	State	Modified: Reduced tree canopy over invaded understorey							
	Expression	Dense seedling eucalypts with invaded understorey		Reduced tree canopy over invaded understorey		Dense pole-stage eucalypt stands		Areal weighted average for the state	
	Year	2010	2015	2010	2015	2010	2015	2010	2015
Physical and chemical	Water persistence (months)	5	5	2	2	5	5	2	2
Structural	Aboveground live biomass (t/ha)	4	4	107	107	–	–	107	107
	Aboveground standing dead biomass (t/ha)	ND	ND	38	38	35	35	37	37
	Average stem diameter (m)	ND	ND	–	–	–	–	–	–
	Canopy cover	NC	NC	NC	NC	NC	NC	45	38
	Canopy cover of second layer (%)	–	–	3	3	10	10	3	3
	Canopy cover of third layer (%)	–	–	50	50	–	–	50	50
	Canopy cover of upper layer (%)	20	20	30	30	50	50	33	32
	Cover of organic litter (%)	ND	ND	60	60	ND	ND	60	60
	Height of second layer (m)	–	–	2	2	2	2	2	2
	Height of third layer (m)	–	–	1	1	–	–	1	1
	Height of upper layer (m)	2	2	23	23	3	3	21	21
	Live basal area (m2/ha)	ND	ND	5	5	5	5	5	5
	Live basal area index	NC	NC	NC	NC	NC	NC	3	4
	Number of large trees (ha-1)	–	–	ND	ND	ND	ND	Na	Na
	Number of structural layers	1	1	3	3	2	2	3	3
	Stand condition score	ND	ND	4	4	4	4	4	4
	Stand condition index	NC	NC	NC	NC	NC	NC	4	3
	Stem density (stems/ha)	ND	ND	67	67	120	120	74	72
	Total basal area (m2/ha)	ND	ND	7	7	7	7	7	7
Composition	Cover of exotic plant species (%)	ND	ND	11	11	–	–	10	10

Type	State	Modified: Reduced tree canopy over invaded understorey							
	Expression	Dense seedling eucalypts with invaded understorey		Reduced tree canopy over invaded understorey		Dense pole-stage eucalypt stands		Areal weighted average for the state	
	Year	2010	2015	2010	2015	2010	2015	2010	2015
	Cover of native plant species (%)	ND	ND	26	26	ND	ND	26	26
	Richness of exotic understorey plant species 100m-2	ND	ND	16	16	–	–	14	15
	Richness of native understorey plant species 100m-2	ND	ND	11	11	ND	ND	11	11
	Woodland bird species richness	ND	ND	92	92	ND	ND	92	92
	Woody cover fraction	NC	NC	NC	NC	NC	NC	–	–
Functional	mean number of months inundated	NC	NC	NC	NC	NC	NC	–	–
	percentage of years inundated (%)	NC	NC	NC	NC	NC	NC	1	–

Note: NA = No area, NC = Not calculated because data is spatially continuous and does not need to be summarised by expression before aggregation, ND = No data, Na = not applicable. Areal weighted average is an area weighted average of the expressions in the state. The areal weighted average is Na if there is a no data value or not applicable value in the row. Woody cover fraction units is proportion of woody plant material. Where there is one expression inside a state, the areal weighted average is equal to the values in the expression. '–' = 0
Source: Harwood et al. (2021a), Prober et al. (2021)

Table 73 Ecosystem condition variable account, 'inland floodplain eucalypt forests and woodland' ecosystem type

Type	State	Modified: Invaded mature floodplain eucalypt forests and woodlands		Modified: Reduced tree canopy cover over invaded understorey *or* Invaded mature floodplain eucalypt forests and woodlands*		Modified: Halophytic state	
	Expression	**Invaded mature floodplain eucalypt forests and woodlands**		**Reduced tree canopy over invaded understorey *or* Invaded mature floodplain eucalypt forests and woodlands†**		**Invaded halophytic shrubland**	
	Year	**2010**	**2015**	**2010**	**2015**	**2010**	**2015**
Physical and chemical	Water persistence (months)	5	5	3	3	ND	ND
Structural	Aboveground live biomass (t/ha)	226	226	128	128	ND	ND
	Aboveground standing dead biomass (t/ha)	52	52	40	40	ND	ND
	Average stem diameter (m)	–	–	–	–	ND	ND
	Canopy cover	54	41	47	55	44	26
	Canopy cover of second layer (%)	3	3	3	3	30	30
	Canopy cover of third layer (%)	50	50	50	50	–	–
	Canopy cover of upper layer (%)	40	40	32	32	35	35
	Cover of organic litter (%)	60	60	60	60	ND	ND
	Height of second layer (m)	2	2	2	2	–	–
	Height of third layer (m)	1	1	1	1	–	–
	Height of upper layer (m)	27	27	24	24	1	1
	Live basal area (m2/ha)	10	10	6	6	ND	ND
	Live basal area index	4	4	3	5	3	2
	Number of large trees (ha-1)	15	15	15	15	ND	ND
	Number of structural layers	3	3	3	3	2	2
	Stand condition score	4	4	4	4	ND	ND

Type	State	Modified: Invaded mature floodplain eucalypt forests and woodlands		Modified: Reduced tree canopy cover over invaded understorey *or* Invaded mature floodplain eucalypt forests and woodlands*		Modified: Halophytic state	
	Expression	**Invaded mature floodplain eucalypt forests and woodlands**		**Reduced tree canopy over invaded understorey *or* Invaded mature floodplain eucalypt forests and woodlands†**		**Invaded halophytic shrubland**	
	Year	**2010**	**2015**	**2010**	**2015**	**2010**	**2015**
	Stand condition index	4	3	4	4	3	3
	Stem density (stems/ha)	72	72	68	68	ND	ND
	Total basal area (m2/ha)	11	11	8	8	ND	ND
Composition	Cover of exotic plant species (%)	11	11	11	11	ND	ND
	Cover of native plant species (%)	26	26	26	26	ND	ND
	Richness of exotic understorey plant species 100m-2	16	16	16	16	ND	ND
	Richness of native understorey plant species 100m-2	11	11	11	11	ND	ND
	Woodland bird species richness	92	92	92	92	ND	ND
	Woody cover fraction	–	–	–	–	–	–
Functional	mean number of months inundated	–	–	–	–	–	–
	percentage of years inundated (%)	1	–	–	3	–	–

Note: NA = No area, NC = Not calculated because data is spatially continuous and does not need to be summarised by expression before aggregation, ND = No data, Na = not applicable. Areal weighted average is an area weighted average of the expressions in the state. The areal weighted average is Na if there is a no data value or not applicable value in the row. Woody cover fraction units is proportion of woody plant material. Where there is one expression inside a state, the areal weighted average is equal to the values in the expression. '–' = 0

*In this area, the extent of the 'reduced tree canopy over invaded understorey' modified state could not be distinguished from the extent of the 'invaded mature floodplain eucalypt forests and woodlands' modified state.

†In this area, the extent of the 'reduced tree canopy over invaded understorey' expression could not be distinguished from the extent of the 'invaded mature floodplain eucalypt forests and woodlands' expression. Values derived from remote sensing data (see pg 60 of this report for the listing of variables) are an aeral weighted average. Inferred data characteristics are a weighted average based on the distribution of expressions on the on-ground monitoring plots: 0.17 and 0.83 for 'invaded mature floodplain forests and woodlands' and 'reduced tree canopy over invaded understorey' expressions, respectively.

Source: Harwood et al. (2021a), Prober et al. (2021)

Table 74 Ecosystem condition variable account, 're-sprouter temperate and subtropical eucalypt woodlands' ecosystem type

Type	State	Modified: Grey box woodlands with exotic understorey	
	Year	**2010**	**2015**
Physical and chemical	Water persistence (months)	–	–
Structural	Aboveground live biomass (t/ha)	99	99
	Aboveground standing dead biomass (t/ha)	2	2
	Average stem diameter (m)	24	24
	Canopy cover	47	28
	Canopy cover of second layer (%)	3	3
	Canopy cover of third layer (%)	40	40
	Canopy cover of upper layer (%)	22.5	22.5
	Cover of organic litter (%)	68	68
	Height of second layer (m)	1	1
	Height of third layer (m)	–	–
	Height of upper layer (m)	30	30
	Live basal area (m2/ha)	6	6
	Live basal area index	4	2
	Number of large trees (ha-1)	13	13
	Number of structural layers	2	2
	Stand condition score	–	–
	Stand condition index	4	3
	Stem density (stems/ha)	100	100
	Total basal area (m2/ha)	6	6
Composition	Cover of exotic plant species (%)	5	5
	Cover of native plant species (%)	25	25
	Richness of exotic understorey plant species 100m-2	4	4
	Richness of native understorey plant species 100m-2	11	11

	Woodland bird species richness	ND	ND
	Woody cover fraction	–	–
Functional	mean number of months inundated	–	–
	percentage of years inundated (%)	1	–

Note: NA = No area, NC = Not calculated because data is spatially continuous and does not need to be summarised by expression before aggregation, ND = No data, Na = not applicable. Areal weighted average is an area weighted average of the expressions in the state. The areal weighted average is Na if there is a no data value or not applicable value in the row. Woody cover fraction units is proportion of woody plant material. Where there is one expression inside a state, the areal weighted average is equal to the values in the expression. '–' = 0. Values for the state are shown here because the extent of expressions within the state could not be distinguished. Values derived from remote sensing data (see pg 60 of this report for the listing of variables) are reported at the level of the ecosystem state. Inferred data characteristics are an average of the values for the two expressions: 'Grey box grassy woodlands with exotic understorey' and 'Grey box shrub-grass woodlands with denuded understorey'.
Source: Harwood et al. (2021a), Prober et al. (2021)

Table 75 Ecosystem condition variable account, 'fire-intolerant *Callitris* woodlands' ecosystem type

Type	State	Modified: High-rise sandhill pine woodlands		Modified: Low-rise sandhill pine woodlands	
	Expression	**Denuded canopy and no understorey strata**		**Senescent *Allocasuarina* over invaded understorey**	
	Year	**2010**	**2015**	**2010**	**2015**
Physical and chemical	Water persistence (months)	–	–	–	–
Structural	Aboveground live biomass (t/ha)	ND	ND	ND	ND
	Aboveground standing dead biomass(t/ha)	ND	ND	ND	ND
	Average stem diameter (m)	–	–	1	1
	Canopy cover	48	41	48	27
	Canopy cover of second layer (%)	–	–	3	3
	Canopy cover of third layer (%)	–	–	40	40
	Canopy cover of upper layer (%)	3	3	40	40
	Cover of organic litter (%)	ND	ND	ND	ND
	Height of second layer (m)	–	–	2	2
	Height of third layer (m)	–	–	–	–
	Height of upper layer (m)	25	25	13	13
	Live basal area index	3	4	3	3
	Live basal area (m2/ha)	ND	ND	ND	ND
	Number of large trees (ha-1)	–	–	3	3
	Number of structural layers	1	1	3	3
	Stand condition index	3	4	2	3
	Stand condition score	ND	ND	ND	ND
	Stem density (stems/ha)	–	–	8	8
	Total basal area (m2/ha)	ND	ND	ND	ND
Composition	Cover of exotic plant species (%)	90	90	20	20

Type	State	Modified: High-rise sandhill pine woodlands		Modified: Low-rise sandhill pine woodlands	
	Expression	**Denuded canopy and no understorey strata**		**Senescent *Allocasuarina* over invaded understorey**	
	Year	**2010**	**2015**	**2010**	**2015**
	Cover of native plant species (%)	ND	ND	ND	ND
	Richness of exotic understorey plant species 100m-2	ND	ND	ND	ND
	Richness of native understorey plant species 100m-2	–	–	25	25
	Woodland bird species richness	ND	ND	ND	ND
	Woody cover fraction	–	–	–	–
Functional	mean number of months inundated	–	–	–	–
	percentage of years inundated (%)	–	1	–	–

Note: NA = No area, NC = Not calculated because data is spatially continuous and does not need to be summarised by expression before aggregation, ND = No data, Na = not applicable. Areal weighted average is an area weighted average of the expressions in the state. The areal weighted average is Na if there is a no data value or not applicable value in the row. Woody cover fraction units is proportion of woody plant material. Where there is one expression inside a state, the areal weighted average is equal to the values in the expression. '–' = 0
Source: Harwood et al. (2021a), Prober et al. (2021)

Table 76 Ecosystem condition variable account, 'wetlands' ecosystem type

Realm	Type	State	Modified: High-condition wetlands		Modified: Moderate- *or* low-condition wetlands†									
		Expression	**High-condition wetlands***		**Permanent wet (moderate-condition)**		**Semi-permanent wet (moderate-condition)**		**Mudflat (moderate-condition)**		**Dirt**		**Areal weighted average for the state**	
		Year	**2010**	**2015**	**2010**	**2015**	**2010**	**2015**	**2010**	**2015**	**2010**	**2015**	**2010**	**2015**
Aquatic	Composition	Abundance of waterbirds	89	89	52	52	67	67	NA	Na	Na	Na	Na	Na
		Cover of exotic plants (%)	.8	.8	.3	.3	1.9	1.9	NA	Na	Na	Na	Na	Na
		Cover of 'high threat' exotic plants (%)	.7	.7	.1	.1	.9	.9	NA	Na	Na	Na	Na	Na
		Cover of native plant species (%)	35.8	35.8	34.7	34.7	25.4	25.4	NA	Na	Na	Na	Na	Na
		Native fish species relative abundance	.5	.5	.5	.5	.5	.5	NA	Na	Na	Na	Na	Na
		Richness of native understorey plant species	20.8	20.8	11.1	11.1	16.2	16.2	NA	Na	Na	Na	Na	Na
		Species richness of native fish	4	4	4	4	2.5	2.5	NA	Na	Na	Na	Na	Na
		Species richness of waterbirds	8	8	5	5	3	3	NA	Na	Na	Na	Na	Na
	Functional	Large-bodied fish age/size class diversity	3	3	3	3	3	3	NA	Na	Na	Na	Na	Na
Terrestrial	Physical and chemical	Water persistence (months)	ND	ND	ND	ND	ND	ND	NA	–	–	–	Na	Na
	Structural	Aboveground live biomass (t/ha)	Na	Na	Na	Na	Na	Na	NA	ND	–	–	Na	Na
		Aboveground standing dead biomass(t/ha)	Na	Na	Na	Na	Na	Na	NA	ND	–	–	Na	Na
		Average stem diameter (m)	Na	Na	Na	Na	Na	Na	NA	–	–	–	Na	Na
		Canopy cover	56.62	58.33	NC	NC	NC	NC	NA	NC	NC	NC	43.1	41.46
		Canopy cover of second layer (%)	Na	Na	Na	Na	Na	Na	NA	–	–	–	Na	Na

	Canopy cover of third layer (%)	Na	Na	Na	Na	Na	Na	NA	–	–	–	Na	Na
	Canopy cover of upper layer (%)	Na	Na	Na	Na	Na	Na	NA	27	–	–	Na	Na
	Cover of organic litter (%)	Na	Na	Na	Na	Na	Na	NA	ND	15	15	Na	Na
	Height of second layer (m)	Na	Na	Na	Na	Na	Na	NA	–	–	–	Na	Na
	Height of third layer (m)	Na	Na	Na	Na	Na	Na	NA	–	–	–	Na	Na
	Height of upper layer (m)	Na	Na	Na	Na	Na	Na	NA	.3	–	–	Na	Na
	Live basal area index	3.68	4.58	NC	NC	NC	NC	NA	NC	NC	NC	3.15	3.65
	Live basal area (m2/ha)	Na	Na	Na	Na	Na	Na	NA	–	–	–	Na	Na
	Number of large trees (ha-1)	Na	Na	Na	Na	Na	Na	NA	–	–	–	Na	Na
	Number of structural layers	Na	Na	Na	Na	Na	Na	NA	1	–	–	Na	Na
	Stand condition index	4.58	3.68	NC	NC	NC	NC	NA	NC	NC	NC	3.71	3.12
	Stand condition score	Na	Na	Na	Na	Na	Na	NA	–	–	–	Na	Na
	Stem density (stems/ha)	Na	Na	Na	Na	Na	Na	NA	–	–	–	Na	Na
	Total basal area (m2/ha)	Na	Na	Na	Na	Na	Na	NA	–	–	–	Na	Na
Composition	Cover of exotic plant species (%)	Na	Na	Na	Na	Na	Na	NA	1.7	–	–	Na	Na
	Cover of native plant species (%)	Na	Na	Na	Na	Na	Na	NA	25.1	–	–	Na	Na
	Richness of exotic understorey plant species 100m-2	Na	Na	Na	Na	Na	Na	NA	4	–	–	Na	Na
	Richness of native understorey plant species 100m-2	Na	Na	Na	Na	Na	Na	NA	16.2	–	–	Na	Na
	Woodland bird species richness	Na	Na	Na	Na	Na	Na	NA	ND	ND	ND	Na	Na
	Woody cover fraction	.35	.5	NC	NC	NC	NC	NA	NC	NC	NC	.33	.25
	mean number of months inundated	.35	.35	NC	NC	NC	NC	NA	NC	NC	NC	.33	.34
	percentage of years inundated (%)	.35	.35	NC	NC	NC	NC	NA	NC	NC	NC	6.41	5.74

Note: NA = No area, NC = Not calculated because data is spatially continuous and does not need to be summarised by expression before aggregation, ND = No data, Na = not applicable. Areal weighted average is an area weighted average of the expressions in the state. The areal weighted average is Na if there is a no data value or not applicable value in the row.
Only wet expressions were observed for 2010 and 2015 for the high-condition wetlands (therefore terrestrial attributes were not applicable). Woody cover fraction units is proportion of woody plant material. The areal weighted average for the 'moderate or low wetlands) assumes that all wet expressions were in moderate-condition. Where there is one expression inside a

state, the areal weighted average is equal to the values in the expression. '–' = 0
*'High-condition wetlands' expression includes an aggregation of terrestrial characteristics across all high-condition wetland expressions; aquatic characteristics represent the 'permanent wet (high-condition)' expression only.
†In this area, the extent of the 'moderate-condition wetlands' modified state could not be distinguished from the extent of the 'low-condition wetlands' modified state. The inferred data characteristics are shown for moderate-condition wetland expressions only. Inferred data for low-condition wetland expressions has not been included because the extent of low-condition wetland expressions could not be identified.
Source: Harwood et al. (2021a), Prober et al. (2021)

Table 77 Ecosystem condition variable account, 'lowland streams' ecosystem type

Type	State	Modified: Managed flows*	
	Year	2010	2015
Physical and chemical	Concentration of total nitrogen (mg/L)	.7	.7
	Concentration of total phosphorus (mg/L)	.5	.5
	Dissolved organic carbon (mg/L)	10	10
	Dissolved oxygen (mg/L)	6	6
	Maximum water temperature (°C)	28	28
	Salinity (µS/cm)	3600	3600
	Silica (mg/L)	5.5	5.5
	Sulphate and bi-carbonate (mg/L)	7	7
	Water pH	7.4	7.4
Structural	Canopy cover	46.69	35.17
	Live basal area index	3.86	4.27
	Stand condition index	4.21	3.94
Composition	Abundance of waterbirds	No data	No data
	Cover of exotic plants (%)	No data	No data
	Cover of 'high threat' exotic plants (%)	No data	No data
	Cover of native plant species (%)	No data	No data
	Native fish species relative abundance	.6	.6
	Richness of native understorey plant species	No data	No data
	Species richness of native fish	6.5	6.5
	Species richness of waterbirds	No data	No data
	Woody cover fraction	.29	.2
Functional	Large-bodied fish age/size class diversity	8.25	8.25
	mean number of months inundated	8.5	9.4
	percentage of years inundated (%)	73.63	81.08

Note: NA = No area, NC = Not calculated because data is spatially continuous and does not need to be summarised by expression before aggregation, ND = No data, Na = not applicable. Areal weighted average is an area weighted average of the expressions in the state. The areal weighted average is Na if there is a no data value or not applicable value in the row. Woody cover fraction units is proportion of woody plant material. Where there is one expression inside a state, the areal weighted average is equal to the values in the expression. '–' = 0

*'River Murray main channel' expression and the 'irrigation supply channel' expression are reported in combination. Values for the state are shown because expressions within the state could not be distinguished. Values derived from remote sensing data (see pg 60 of this report for the listing of variables) are an aeral weighted average for the state. Expert derived characteristics are an average of the values for the two expressions.

Source: Harwood et al. (2021a), Prober et al. (2021)

12 Glossary

TERM	DEFINITION
Archetype model	conceptual model that describes the endogenous disturbance dynamics and ecosystem expressions that characterise ecosystems with integrity. These models are not operational and cannot be directly or solely used for measurement or mapping but provide a template for reference and modified states in state and transition models. (Richards et al., 2020)
Attribute	see 'ecosystem attributes'
Australian Ecosystem Models Framework	a standardised approach to collate, synthesise and summarise scientific knowledge on ecosystem dynamics in a set of conceptual models. These models describe the dynamic characteristics and drivers of Australian ecosystems in reference and modified states, as defined by (Richards et al. 2020).
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; UNCEEA 2021)
Community-level biodiversity	consideration of biodiversity for an assemblage of species within a taxonomic group at a location
Compositional similarity	the similarity in the assemblages of species occurring in different locations. In the present study, compositional similarity is considered in terms of pairs of locations.
Conceptual model	abstraction of reality that uses descriptions of system parts and their interactions to condense complex systems and processes into a format that allows more general understanding (BoM 2016; Tilden et al. 2012). In ecology, they offer a flexible and simple way to summarise and communicate current understanding of ecosystem behaviour and enable identification of knowledge gaps. Conceptual models can also be used to explain historical ecosystem changes and help to predict future changes (Vankat 2013). By removing complex details, conceptual models may assist in the discovery of patterns and the development of generalised characterisations of systems.
Disturbance	discrete event (in both space and time) that resets an ecosystem; that is, it disrupts ecosystem, community or population structure and changes resources, substrate availability or the physical environment (Hobbs and Huenneke 1992; White and Pickett 1985). Disturbances are described by a regime, including frequency, intensity, duration, extent and timing. In contrast, a perturbation is 'any change in a parameter (state variable) that defines a system; that is, a departure (explicitly defined) from a normal state, behaviour, or trajectory (also explicitly defined)' (White and Pickett 1985 p.5). While the terms 'disturbance' and 'perturbation' are sometimes used interchangeably, we will use the term 'disturbance' to denote a causal event that is temporary and localised, while terms like 'perturbation' or 'stress' are restricted to describing an effect or response of an ecosystem to a disturbance event or other ecological process (Rykiel 1985). Thus, climate change may be a stress to biodiversity, but droughts, which are predicted to increase in frequency and duration under climate change in many regions (Lemoine et al. 2016; Trenberth et al. 2014), are the potential sources of disturbance (Dornelas 2010).

TERM	DEFINITION
Driver	a factor that causes a particular phenomenon to happen or develop. In the case of the Australian Ecosystem Models Framework (Richards et al. 2020), a driver may be a management action or a threatening process that results in a transition between ecosystem states.
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 (UNCEEA 2021) (compare 'ecosystem integrity')
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	the geographical territory for which an ecosystem account is compiled (UNCEEA 2021)
Ecosystem asset	a contiguous space of a specific ecosystem type characterized by a distinct set of biotic and abiotic components and their interactions (UNCEEA 2021)
Ecosystem attributes	the biotic and abiotic properties and functions of an ecosystem (grouped into physical conditions, species composition, community structure, ecosystem function and external exchanges) (McDonald et al. 2016) 'Ecosystem attributes' are equivalent to 'ecosystem characteristics' in the SEEA-EA standard (UNCEEA 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 (UNCEEA 2021)
Ecosystem characteristic	a system property of the ecosystem and its major abiotic and biotic components (water, soil, topography, vegetation, biomass, habitat and species) with examples of characteristics including vegetation type, water quality and soil type (UNCEEA 2021)
Ecosystem condition	the quality of an ecosystem measured in terms of its abiotic and biotic characteristics (UNCEEA 2021) 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. 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 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 indicator	rescaled version of ecosystem condition variables (UNCEEA 2021)
Ecosystem condition characteristic	an ecosystem characteristic that is relevant for the assessment of ecosystem condition (UNCEEA 2021)
Ecosystem condition typology	a hierarchical typology for organising data on ecosystem condition characteristics (UNCEEA 2021)

TERM	DEFINITION
Ecosystem condition variable	a quantitative metric describing individual characteristics of an ecosystem asset (UNCEEA 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 (UNCEEA 2021)
Ecosystem dynamics	ecosystem patterns and processes that are driven by disturbance and recovery (Battisti et al. 2016). Different stages of ecosystems along pathways of disturbance and recovery are termed 'ecosystem expressions'.
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 size of an ecosystem asset in terms of spatial area (UNCEEA 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 (UNCEEA 2021)
Ecosystem state	the manifestation of an ecosystem at a particular point in space and time
Ecosystem type	In the SEEA-EA standard: an ecosystem type reflects a distinct set of abiotic and biotic components and their interactions (UNCEEA 2021). In AusEcoModels Framework: a unit of an ecosystem classification defined by the ecosystem characteristics (for example, facets of structure, function, composition) that characterise the reference state for a given scale of organisation, for example defined by its discrete disturbance and recovery dynamic (Richards et al. 2020; Kay 1991). An ecosystem type, once defined, may be spatially identified and mapped.
Endogenous disturbance	a disturbance internal to an ecosystem (Rogers 1996) that maintains ecosystem integrity. They include fire, drought, floods, cyclones, storms, erosive and depositional processes, heatwaves, cold snaps, chemical intrusion and biotic outbreaks. They characterise ecosystems in the Australian environment prior to processes that have driven the homogenisation of ecosystems (an era termed the 'Homogenocene') and may be driven by anthropogenic (for example, ecological fire management) or non-anthropogenic (climate) processes.
Environmental water	share of water that can be used to achieve environmental outcomes (MDBA 2012)
Exogenous disturbance	a disturbance external to an ecosystem (Rogers 1996) that can trigger transitions from the reference to modified states (with lower ecosystem integrity) by transforming transient disturbances into persistent disturbances (for example, switching from macropod grazing regimes to continuous cattle grazing), introducing new disturbances that result in chronic stress on an ecosystem (for example, habitat fragmentation from land clearing) or suppressing important disturbance events (for example, fire suppression near urban areas) (Suding and Hobbs 2009). Exogenous disturbances are driven by anthropogenic actions associated with the Homogenocene.

TERM	DEFINITION
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).
Homogenocene	an era within which the Earth is experiencing rapid loss of its unique biological and cultural heritage, whilst its ecosystems and cultures are being increasingly homogenised (Curnutt 2000; Samways 1999). The international start date for this era is identified as 1493, when germs, plants, animals and cultures began to be exchanged around the globe. Ecosystem homogenisation is in part attributed to transference of common agricultural and invasive species around the globe, along with other drivers such as land clearing. The onset and intensification of ecosystem homogenisation processes varies across continents and regions – in Australia, most notably since European colonisation and subsequent settlement history.
Integrity	see 'ecosystem integrity'
Land cover	the observed physical and biological cover of the Earth's surface, including natural vegetation and abiotic (non-living) surfaces (United Nations 2014, para. 5.257)
Management action	deliberate action undertaken by people to alter aspects of an ecosystem, often resulting in the transition from one ecosystem state to another. One or more management actions may be part of an exogenous disturbance.
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 (UNCEEA 2021)
Reference disturbance	see 'endogenous disturbance'
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 (UNCEEA 2021)
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 attributes and endogenous disturbance regimes, compared to the archetype model.
Species richness	the number of species occurring in a location, typically considered within a specific taxonomic group
Species-level biodiversity	consideration of biodiversity for each individual species separately
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 (Westoby et al. 1989; Stringham et al. 2003;

TERM	DEFINITION
	Bestelmeyer et al. 2017). 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 (for example, 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; Bestelmeyer et al., 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).
Threatening process	a process that causes or may cause a transition from one ecosystem state to another, resulting in reduced ecosystem condition
Transition	change between ecosystem states
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)

13 Suite of reports and data for Gunbower-Koondrook-Perricoota Forest Icon Site

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