Northern Australia Environmental Resources Hub

National Environmental Science Programme

Environmental economic accounting for interconnected ecosystem assets and ecosystem services in the Mitchell River catchment, Queensland

Technical report – Methodology

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This report should be cited as:

Smart, J.C.R., Hasan S., Dyke J., Sinnamon V., Jackson S., Barber M., McMahon J.M., Brown C.J., Curwen G.R., Saint Ange C., Burns G.L., Fleming C.M., Connolly R.M., Burford M.A. (2022) *Environmental economic accounting for interconnected ecosystem assets and ecosystem services in the Mitchell River catchment, Queensland: Technical report – Methodology.* Griffith University, Brisbane.

Cover photographs

Front cover: Mitchell catchment, Queensland, Australia (photo: Chantal Saint Ange)
Back cover: Mitchell catchment, Queensland, Australia (photo: Graeme Curwen)

This report is available for download from the Northern Australia Environmental Resources (NAER) Hub website at nespnorthern.edu.au

The Hub is supported through funding from the Australian Government's National Environmental Science Program (NESP). The NESP NAER Hub is hosted by Charles Darwin University.

August, 2022

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Acronyms

ABS	Australian Bureau of Statistics
ALUM	Australian Land Use and Management
BSU	Basic Spatial Unit
BVG	Broad vegetation group
DoEE	Department of Environment and Energy
DAWE	Department of Agriculture, Water and Environment
EA	Ecosystem asset
EAA	Ecosystem accounting area
EFG	Ecosystem functional group
ET	Ecosystem type
GVAP	Gross value of agricultural production
IUCN	International Union for Conservation of Nature
IUCN GET	International Union for Conservation of Nature Global Ecosystem Typology
LGA	Local Government Area
MDWSS	Mareeba Dimbulah Water Supply Scheme
NAWRA	Northern Australia Water Resource Assessment
NESP	National Environmental Science Program
QLUMP	Queensland Land Use Mapping Program
RE	Regional ecosystem
SA	Statistical area
SEEA	System of Environmental-Economic Accounting
SEEA-CF	System of Environmental-Economic Accounting – Central Framework
SEEA EA	System of Environmental-Economic Accounting – Ecosystem Accounting
SNA	System of National Accounts

Acknowledgements

We gratefully acknowledge the assistance provided by other members of the project 4. team in helping to generate the ideas and implementations described in these accounts. We acknowledge the assistance provided by colleagues who contributed their research experience from projects on multiple aspects of the Mitchell catchment under the National Environmental Science Program (NESP), National Environmental Research Programme and the Tropical Rivers and Coastal Knowledge research consortium. We thank stakeholders in the Mitchell catchment (natural resource management groups and local communities) for their enthusiastic support of this project and their willingness to contribute data and expertise. We also wish to thank the NESP Northern Australia Environmental Resources Hub (NAERH) team and the NESP NAERH Queensland Regional Research Coordinator for their invaluable advice and assistance.

The Kowanyama community generously provided project Research Associate and longstanding Kowanyama resident and collaborator Viv Sinnamon with information about the ways in which Traditional Owners care for Country in the lower Mitchell catchment and delta, and with details of how their ability to conduct multiple on-Country activities has been impacted by the increasing presence and prevalence of feral animals and invasive weeds. The researchers recognise that this information is valued for its cultural significance to its custodians.

Dr John Neldner of the Queensland Herbarium provided essential advice on relating Queensland's Remnant Regional Ecosystems classifications to the IUCN Global Ecosystem Typology's Ecosystem Functional Groups.

This project was funded through the Northern Australia Environmental Resources Hub of the Australian Government's National Environmental Science Program.

This report contains information contributed by Indigenous Traditional Owners from the vicinity of Kowanyama in the Mitchell River delta. Information and data contributed by Indigenous Traditional Owners from the vicinity of Kowanyama and presented in this report as written text, tables and maps remain the property of those Traditional Owners (or of their families in circumstances where they are deceased). Information and data contributed by Indigenous Traditional Owners from the vicinity of Kowanyama must not be reproduced from this report, nor should these data be extracted and re-analysed in any way, without obtaining prior informed consent from the Traditional Owners through the Kowanyama Aboriginal Land and Natural Resource Management Office and Abm Elgoring Ambung RNTBC.

Aboriginal and Torres Strait Islander people should be aware that this report contains the names of deceased persons who are cited as authoritative sources for land management practices and ecosystem extent and condition.

Executive summary

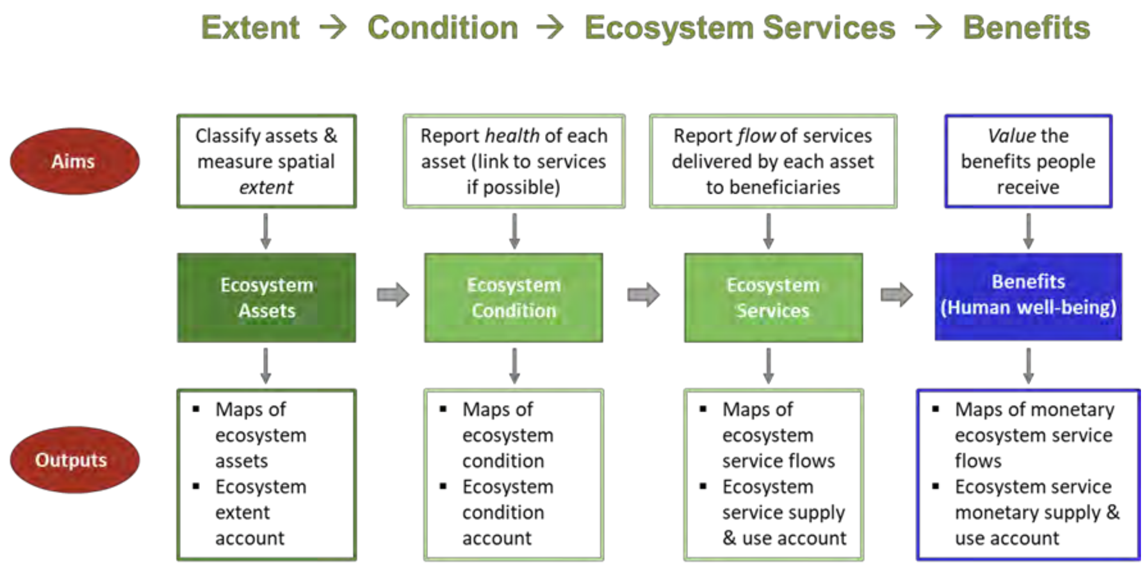
For tens of thousands of years prior to European invasion and settlement, the ancestors of today's Traditional Owners of the Mitchell catchment socialised the landscapes of the region as they managed land and water, fulfilled custodial responsibilities under customary law and maintained an economic system that sustained their way of life. This active management by Traditional Owners continues in many localities today, albeit under constrained conditions. As one example, Traditional Owners' expertise in savanna fire management has abated carbon emissions and generated an average of $3.5 million annually across the Mitchell catchment over the past eight years through supply of global climate regulating services.

Whilst acknowledging conceptual misalignments, it is important to recognise that Ecosystem Accounts provide a potential opportunity for documenting and reporting the contribution of Indigenous Traditional Owners in managing Country in ways that enhance supply of many ecosystem services that benefit human society. Ecosystem Accounts also have the potential to track changes in ecosystem condition and the multiple pressures that affect condition. This could be particularly relevant for Indigenous communities because of their strong relationship with and dependence upon Country and the emergence of contemporary Indigenous natural resource management in Australia over the last three decades in which traditional knowledge and mainstream science are combined.

More broadly, considerations of morality, history, and scientific accuracy make it essential to consider how Indigeneity is made visible in Ecosystem Accounts. Colonial contexts like Australia usefully highlight how an extended history of Indigenous management of landscapes has been disrupted by much shorter periods of subsequent aggressive colonisation, with consequences for landscape change, human management, and ecosystem service provision. Sensitivity to Indigeneity provides more nuanced understanding of the assumptions underlying estimates of baseline conditions, the ways in which actors and their activities are rendered (in)visible in accounting practices, and the potential future options for improvement in asset condition and service provision. As such, Ecosystem Accounting research in Australia's north – where Indigenous populations have high levels of reliance on ecosystem assets – could thus be very informative, nationally and internationally.

In line with the Australian Government's Strategy and Action Plan for Environmental Economic Accounting, NESP Project 4.6 applied the United Nations Statistics Division's System of Environmental Economic Accounting (SEEA) methodology to produce a set of pilot Ecosystem Accounts for the Mitchell River catchment in far north Queensland. An accompanying 'Pilot ecosystem accounts and supporting information' report presents the pilot set of accounts themselves and reflects on their potential use for informing policy direction. A separate 'Data Inventory' provides metadata and additional details of the data used in account construction. This report describes the methodologies used to compile the pilot accounts and reflects on learnings obtained from data collation and account construction.

SEEA Ecosystem Accounts (SEEA EA) are designed to be fully compatible with the United Nations Statistics Division's System of National Accounts (SNA) for standardised reporting of the performance of national economies. SEEA EA comprise a set of spatially linked accounts, and accompanying maps, that report the *extent* and *condition* of *ecosystem assets* (individual blocks of woodland, grassland etc.), grouped by *ecosystem type*, within a defined ecosystem accounting area, together with tables and maps that report the *supply of ecosystem services* from the different ecosystem types and their *use* by businesses, households and governments. Supply and use of ecosystem services are reported in *biophysical* and *monetary* units.



SEEA EA regards ecosystem services as *ecosystems' contributions to benefits* that are delivered to human society. Before the advent of Ecosystem Accounting these contributions from ecosystems were largely absent from national accounts. The 'transactional' and 'linear' interaction paradigm that underpins SEEA Ecosystem Accounts is evident in the above figure – 'benefits via contributions *from* ecosystems *to* people'. This contrasts with Indigenous Traditional Owners' relationship with Country in which, guided by customary law, they care for Country as an ongoing manifestation of ancestral power and in recognition of their obligations to future generations. We argue a concept of co-production would be a more accurate expression of this relationship.

Key data and methodologies used to compile each SEEA EA account for the Mitchell were as follows:

Ecosystem asset extent account

Data

Spatial polygon data (comprising more than 44,000 polygons) on Remnant Regional Ecosystems, categorised into Broad Vegetation Groups at 1:1,000,000 scale, were readily available for the Mitchell catchment via the Queensland Government's 'Queensland Globe' GIS data portal.

Method

A cross-walk was undertaken to establish equivalences between ecosystem types in the Remnant Regional Ecosystems ecosystem mapping under the Queensland Broad

Vegetation Groups classification and the equivalent ecosystem functional groups categorised under the IUCN's Global Ecosystem Typology (as the required classification for ecosystem asset types in SEEA EA). Expert advice kindly provided by Dr John Neldner of the Queensland Herbarium was extremely valuable here. Ecosystem assets are grouped by ecosystem type to report the total extents (in ha) of each ecosystem type in the extent account. Ecosystem extents, conditions and services flows are reported for 16 ecosystem types in the Mitchell. Extents are reported for a pre-clearing (~1750) baseline and for post-clearing (~2015). A change-in-extent matrix, by ecosystem type, from pre- to post-clearing was also constructed.

Ecosystem asset condition account

Data

A Stage 1 (Variables) Condition Account comprises data on variables that reflect abiotic (physical and chemical), biotic (compositional, structural and functional) and landscape characteristics of asset condition. Condition variables for each ecosystem type were identified, using guidance from SEEA EA and published literature. Selected variables were publicly available at comparable spatial resolution to individual assets across the full extent of the relevant ecosystem type in the catchment. Ideally, data for all selected variables would be available for the same years across all assets.

Method

A Stage 2 (Indicators) Condition Account would feature variables from the Stage 1 (Variables) Condition Account for which normative interpretations and reference levels for 'best' and 'worst' condition could be defined. It would then be possible to express all indicators as scores on a common scale (e.g., 0 to 100). However, within Project 4.6 it was not possible to conduct detailed discussions with ecologists familiar with the relevant ecosystem types to establish the necessary normative interpretations and reference levels, so a Stage 2 (Indicators) Condition Account was not constructed for the Mitchell.

Ecosystem services supply and use account in biophysical terms

The data and methodologies used to produce Ecosystem Services Supply and Use Accounts – in biophysical and monetary terms – differ depending on the category of ecosystem service concerned: provisioning, regulating and cultural. SEEA EA require that users must benefit from an ecosystem service if that service is to be reported in the supply and use tables. A consequence for sparsely populated catchments like the Mitchell is that several services such as flood regulation that would benefit large populations in many catchments on Australia's east coast are absent from the Mitchell accounts. It is also important to note that SEEA EA's conceptualisation of humans solely as *users* of ecosystem services is not consistent with Indigenous Traditional Owners' conceptualisation of the reciprocal relationship between custodians and Country – and, consequently, of ecosystem services being sustained through co-production within that reciprocal relationship. Key data and methodologies for construction of a supply and use account in biophysical terms were as follows.

Data

Provisioning services

Data on biophysical supply of provisioning ecosystem services that are inputs to joint production processes[1] that produce marketed outputs (e.g., harvests by commercial fisheries, ecosystems' contributions to agricultural production) should, in principle, be relatively easy to obtain. In practice, this was considerably easier for some services (e.g., biomass provisioning to the commercial barramundi fishery for which data were readily available for download from the government department that manages the resource) than for others (e.g., crop provisioning services into irrigated agriculture).

Regulating services

Data on the contribution of carbon storage to the global climate regulation service were readily available via remote sensing. Data on carbon sequestration were obtained from the Federal Government registry of land management projects that were commissioned specifically for this purpose. Estimated supply of other regulating services, e.g., soil retention or flood regulation, would typically have to be obtained via biophysical modelling. SEEA EA-aligned modelling platforms such as ARIES, InVEST and The Nature Braid are readily available for this purpose, with a recently published SEEA 'Guidelines' document providing an overview of their application and use. A substantial set of data on ecosystem extent and condition, together with socio-demographic and socio-economic data relating to demand for the services supplied, are required to drive these models. Remotely-sensed data sets – many with global coverage – are potential sources for these data, augmented by Australia-specific data from Digital Earth Australia via their Open Data Cube. Consultation with relevant experts is recommended to help determine which data sources are most appropriate for providing locally relevant data to drive modelled estimation of biophysical service supply from individual ecosystem assets.

Cultural services

To date, SEEA EA evaluation of cultural ecosystem services has focused mainly on recreation-related services, for which data on visitation rates are generally available, albeit at relatively coarse spatial resolution. We note that co-production under the reciprocal relationship between Traditional Owners and Country gives rise to several different categories of cultural ecosystem services – when using SEEA EA concepts and terminology. These services can potentially be accommodated within SEEA EA, either via a link to cultural identity, or by introducing *caring for Country*, *knowing that Country is being cared for*, and *knowing that Country will continue to be cared for*, as cultural ecosystem services in their own right in the 'other cultural services' category.

Method

Provisioning services

Biophysical supply of provisioning ecosystem services in the Mitchell accounts was quantified either directly from data (e.g., barramundi catch in the commercial fishery), or via

[1] A 'joint production process' is a production process in which benefits are produced using inputs from ecosystems *in combination with* human inputs (e.g., equipment, labour, energy).

straightforward construction from data (e.g., offtake of grazing biomass derived from estimated cattle numbers). In the Mitchell Accounts, biophysical supply of provisioning services was not linked back to the condition of the ecosystem assets that supplied the services. This 'missing link' to ecosystem condition was not problematic for constructing biophysical supply and use accounts. It would, however, have been problematic if the intention had been to construct an *ecosystem asset valuation account* in which the predicted biophysical supply of services into the future would have to be consistent with defined scenarios for climate, land management, economic development and socio-demographics (and their consequent impacts on ecosystem extent and condition) in the accounting area.

Regulating services

As noted above, where relevant data are available, SEEA EA-aligned modelling platforms can potentially be used to predict biophysical supply of regulating ecosystem services. However, McMahon et al's findings from Project 4.6[2] regarding the potential performance of an InVEST-type model in predicting supply of soil erosion control services in the Mitchell catchment suggest that, wherever possible, service supply predictions from these types of modelling platforms should be compared against all available service supply data for the locality being modelled. Topic specialists should also be consulted to determine whether the models implemented in commonly used platforms are appropriate for estimating supply of the relevant service(s) in the accounting area being studied.

Cultural services

Methods are evolving which use social media data to estimate supply of cultural services, principally for recreation-related services, but more recently also extending to other categories of cultural services.

Ecosystem services supply and use account in monetary terms

For consistency with standard National Accounts, SEEA EA adopts an *instrumental value* paradigm, within which valuations of ecosystem services must be based on the concept of *exchange value*. Biophysical service supplies (e.g., tonnes of fish catch, tonnes of carbon sequestration, number of visitor days) are multiplied by their respective *exchange prices* to produce *exchange values*. For marketed goods, exchange value can be calculated directly from market pricing. For goods or services that are not transacted in markets, e.g., soil retention, flood regulation, an *exchange-equivalent price* has to be determined. Key data and methodologies for constructing supply and use accounts in monetary terms for the Mitchell were as follows.

Data

Provisioning services

Provisioning services that are inputs to joint production processes that produce marketed outputs are valued as the remainder or '*residual*' after the costs of all other inputs to the production process have been subtracted from the market revenue obtained from sale of the product. This requires that the market revenue from production is known, together with the

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[2] doi.org/10.1016/j.jenvman.2022.115102

cost of all other inputs e.g., fuel, fertiliser, employees' wages, return to the business owner, capital depreciation, and the opportunity cost of capital. Many of these data can be obtained relatively easily, but the required return to the business owner and the capital investment required to setup the business are typically more challenging to quantify.

Regulating services

As most regulating ecosystem services cannot be valued via market pricing (carbon sequestration via human-induced sequestration projects is an exception), appropriate exchange-equivalent prices will typically have to be obtained via non-market valuation, as described under *Methods* below.

Cultural services

Visitors' expenditures can be used within SEEA EA as a proxy for valuation of recreation-related cultural ecosystem services. These data are typically available at relatively coarse spatial resolution from Tourism Research Australia.

Method

Provisioning services

A consequence of using the residual method to value ecosystem services' contributions to joint production processes is that the size of the 'residual' will be affected by changes in production (e.g., changes in crop yield or fish catch) and by changes in the market prices for the produced output and all other inputs into the production process. Consequently, it is likely that residual-based valuations will fluctuate considerably between years. This is not in itself a problem; however, depending on the relative importance of provisioning services in the ecosystem accounting area studied, it could introduce considerable volatility into the time series of annually-reported gross ecosystem product.

Regulating services

Where location-specific data for estimating exchange-equivalent prices for regulating ecosystem services are not available, it is likely that the necessary prices will be derived via some form of benefit transfer from the literature. SEEA EA's requirement to report only exchange values means that valuation-derived pricing should only be transferred from prior studies that used valuation methods that generate exchange values (as opposed to welfare values). This necessitates careful, well-informed selection of studies from the literature as the basis for benefit transfers. Expert advice may well be required here.

Cultural services

When using average visitor expenditures as the basis for valuing recreation-related cultural services, it may not be possible to distinguish expenditures on recreational experiences that benefitted from ecosystem inputs from those that did not. Some valuation ambiguities will likely result.

Further research findings

This document also reports findings from investigations to determine (i) whether SEEA EA compliant condition indicators can be configured appropriately to report on the condition of interlinked ecosystem assets (e.g., rivers, floodplains and wetlands) in an environment that experiences considerable inter-annual variability, and (ii) whether mechanisms can be developed to produce meaningful SEEA EA-compliant valuations of cultural ecosystem services relevant to Indigenous communities.

Using the interlinked suite of ecosystem assets that contribute to production of the barramundi stock for harvest by the commercial fishery in the Mitchell estuary as an example, research by Brown et al.[3] in Project 4.6 concluded that, in settings like the Mitchell with high inter-year variability in key environmental parameters, it would take more than 10 years for a persistent human-induced change in condition to invoke a change in *biophysical* service supply that was large enough to be discerned convincingly from the background of natural inter-year variability. This suggests that it may well take several decades of consistent human-induced change before a change in the (likely more volatile) *monetary* value of service supply could be identified. Consequently, where inter-annual variability is high, we recommend that condition indicators should not be used to inform on reactions to human pressures that cause degradation. Other more responsive indicators are needed to inform actions in a timely manner. Pressure indicators themselves may be better suited to this task, and so may appropriately calibrated predictive models.

The challenges inherent in constructing ecosystem condition indicators is likely to have significant implications for construction of a SEEA-compliant *asset value* account (in which the value of ecological assets would be expressed in monetary terms). In a SEEA EA asset value account, the value of ecological assets would be calculated as the discounted sum of the (monetary) value of the suite of ecosystem services those assets produce over a defined time frame into the future (e.g., 25 years into the future). Given the challenges outlined above in: (i) estimating asset condition, (ii) modelling linkages between asset condition and biophysical service flow, and (iii) calculating the monetary value of service flows, it will be extremely difficult to estimate the value of ecosystem assets reliably into the future. In this context, estimated asset values are likely to be determined mainly by the future scenarios assumed for key biophysical and socio-economic/socio-demographic drivers, rather than arising primarily from the interacting dynamics of the accounting area's socio-ecological systems.

Representing cultural ecosystem services relevant to Indigenous communities is particularly challenging within the SEEA EA framework. SEEA EA adopts a distinctly *linear* perspective on human interactions with ecosystems, focused on the flow of ecosystem services *from* ecosystems *to* human society. In contrast, Indigenous Traditional Owners' conceptualisation is *reciprocal* and *relational*, with reciprocal responsibilities between custodians and Country. The values that arise from those reciprocal interactions are grounded in the fundamental relationship between custodians and Country. With regard to Indigenous Australia, the labour and practices of Indigenous communities have been framed as the means by which some Australian Indigenous communities *co-produce* ecosystem services. The ontological category of 'nature' cannot be taken for granted as a source of ecological stocks and flows. Instead, Indigenous peoples *co-produce* with Country and ecosystem services flow *from that relation*. The concept of *co-production* recognises that responsibilities under customary law require custodians to care for Country appropriately in order for Country to continue to provide ecosystem services. The *bi-directional* nature of the relationship between custodians

[3] biorxiv.org/content/10.1101/2021.07.19.453015v2

and Country forms the basis for a reconceptualising of the interdependencies between custodians, Country and ecosystem service flows.

Given our understanding of the ways in which Indigenous peoples conceptualise socio-ecological relations, we acknowledge that Indigenous perspectives cannot be incorporated into SEEA EA in any straightforward way. However, these conceptualisations of ecosystem service value could be accommodated to some extent as cultural ecosystem services within SEEA EA, by introducing *caring for Country*, *knowing that Country is being cared for*, and *knowing that Country will continue to be cared for*, as cultural ecosystem services in the 'other cultural services' category. This approach would make reciprocal '*services to ecosystems*' explicit as a value delivery mechanism within SEEA EA, and would thus evidence the importance of *reciprocity* and *relational value* to Traditional Owners.

In Project 4.6 we considered two SEEA EA-compliant approaches that could potentially be used to provide a partial representation of the values that Traditional Owners and Indigenous communities might derive from *caring for Country*, *knowing that Country is being cared for*, and *knowing that Country will continue to be cared for*, as cultural ecosystem services. These approaches were: (i) a *cost of inputs* approach (akin to that used in standard National Accounts for valuing provision of health services (i.e., 'caring for people')), and (ii) an *opportunity cost of outputs* approach.

The initial intention in Project 4.6 was to explore these valuation approaches, and collect relevant data for valuation, through workshop discussions and data collection with Traditional Owners and households in Kowanyama. Unfortunately, the intended workshops were not held due to Covid-19 concerns. As we were unable to conduct workshops and discussions with the Kowanyama community, we do not know whether either of our suggested valuation approaches – and the partial representations of the value of on-Country activities that they could produce – would be meaningful and acceptable to Traditional Owners and the Kowanyama community. Lacking the necessary dataset, and without an endorsement of the appropriateness (or otherwise) of the proposed methodologies from the Kowanyama community, we did not implement these valuation approaches in Project 4.6. The suggested methodologies – as detailed in this Report – remain opportunities for future collaborative research.

Project 4.6 materials

There are three main reporting outputs from Project 4.6:

- A report detailing the pilot set of SEEA Ecosystem Accounts for the Mitchell catchment, together with relevant supporting information.
- A technical report that provides further details of the methodologies used to produce the pilot set of SEEA Ecosystem Accounts for the Mitchell catchment (**this document**).
- A data inventory listing the data sources used to compile the pilot set of SEEA Ecosystem Accounts for the Mitchell catchment.

This document is intended to provide detailed descriptions of the methodologies that were used to produce the pilot set of ecosystem accounts for the Mitchell catchment. It should be read in conjunction with the pilot set of accounts.

The data inventory provides metadata and further detail on data sources.

1. Introduction

Population growth, urbanisation, and climate change are placing increasing pressure on finite natural resources and reducing the ability of ecosystems to sustain delivery of a range of ecosystem services that are highly valued by society. Ecosystem services are ecosystems' contributions to material and non-material benefits delivered to individuals and hence contribute to overall societal wellbeing. Ecosystem services are broadly categorised into provisioning (e.g., timber harvests, fish catches, wild-produced foods), regulating (e.g., air and water filtration, flood mitigation), cultural (e.g., recreation, aesthetic and spiritual) and supporting (e.g., soil formation, carbon, nitrogen and water cycling) service categories (Haines-Young & Potschin, 2018; MEA, 2005).

Many provisioning ecosystem services are inputs to the production economy (e.g., catches from wild-capture fisheries and timber harvests from natural forests), but in conventional national accounts (Australian Bureau of Statistics, 2021a) the value they provide is usually assigned to the primary production sector that harvests these service flows, without any acknowledged spatial link back to the ecosystem that actually provided the service. Consequently, the value contributed to society by the underlying ecological assets is not evident (Lars Hein, Obst, Edens, & Remme, 2015). For example, the value generated by barramundi catches appears in national accounts as part of the revenue generated by the commercial fishery sector rather than being attributed back to the ecosystem assets[4] (i.e., the particular stretches of estuary) that supplied the harvested catch of barramundi.

Most regulating ecosystem services, and many cultural ecosystem services, have many of the characteristics of public goods that deliver benefits to society directly, without ever entering the production economy (e.g., climate regulation, storm buffering, air filtration, artistic inspiration from iconic landscapes, beach-based recreation) (Bateman, Mace, Fezzi, Atkinson, & Turner, 2011). The values of the regulating service flows supplied for example by forests, mangrove wetlands, inspirational landscapes, beaches etc. sits 'outside the production boundary' of the economy (Lars Hein et al. 2015; Obst, Hein, & Edens, 2016) and is therefore not captured in national accounts. National accounts thus provide an incomplete reflection of the value that ecosystem types such as forests, grasslands, wetlands, lakes and rivers supply to society. This is problematic because national accounts are used to inform discussion around policy direction, with the ultimate objective of devising policies to achieve sustained economic growth, societal wellbeing and prosperity into the future.

It is, however, becoming increasingly difficult to sustain economic growth, wellbeing and prosperity because the condition of many ecosystem assets is deteriorating. This impairs their ability to sustainably deliver valuable ecosystem services (Lampert, 2019). This may be partly due to a lack of readily accessible and consistent information to inform policy-makers about the extent and condition of ecosystem assets of different ecosystem types and about the value that ecosystem service flows from those assets contribute to society. Efficient economic management may require that the condition of ecosystem assets, and ecosystem types as a whole, is maintained, or the condition of currently degraded assets is enhanced,

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[4] Ecosystem assets are individual patches of a particular ecosystem type. Separate blocks of woodland are ecosystem assets of a defined ecosystem type e.g., temperate woodlands, or tropical/subtropical dry forests and thickets. Ecosystem types are mutually exclusive.

through appropriate land management to demonstrate prudent public investment. Reliable information on trends in the extent and condition of ecosystem assets within ecosystem types, and trends in the supply of ecosystem services from those ecosystem types is thus vital to help inform policy direction for appropriate investment (Guerry et al. 2015). The Australian Government's Environmental Economic Accounting National Strategy and Action Plan (Commonwealth of Australia, 2018) (summarised in Figure 1) aims to rectify this information deficit and facilitate improved support for policy discussion and policy development.

Whilst acknowledging conceptual misalignments, it is important to recognise that Ecosystem Accounts provide a potential opportunity for documenting and reporting the contribution of Indigenous Traditional Owners in managing Country in ways that enhance supply of many ecosystem services that benefit human society. Ecosystem Accounts also have the potential to track changes in ecosystem condition and the multiple pressures that affect condition. This could be particularly relevant for Indigenous communities because of their strong relationship with and dependence upon Country.

More broadly, considerations of morality, history, and scientific accuracy make it essential for Ecosystem Accounts to consider how Indigeneity is made visible in such accounts. Colonial contexts like Australia usefully highlight how an incredibly long extended history of Indigenous management of landscapes has been disrupted by much shorter periods of subsequent aggressive colonisation, with consequences for landscape change, human management, and ecosystem service provision. Sensitivity to Indigeneity provides more nuanced understanding of the assumptions underlying estimates of baseline conditions, the ways in which actors and their activities are rendered (in)visible in accounting practices, and the potential future options for improvement in asset condition and service provision. As such, Ecosystem Accounting research in Australia's north – where Indigenous populations have high levels of reliance on ecosystem assets – could thus be very informative, nationally and internationally.

Figure 1 shows how the National Strategy and Action Plan for Environmental Economic Accounting conceptualises that the type, extent and condition of different ecosystem assets affect the flow of ecosystem goods and services from those assets. Asset condition is affected by historical and current land management. This in turn affects the level of ecosystem services supplied by an asset and – collectively – by ecosystem assets within each ecosystem type, in the form of ecosystems' contributions to benefits to community, government and businesses. Ecosystems' contributions to these benefits can be measured using appropriate market transactions or compatible non-market valuation techniques.

A first step towards producing consistent information on the extent and condition of ecosystem assets, grouped by ecosystem type, and on supply of ecosystem services by those ecosystem types, is to periodically compile and collate relevant information on the extent and condition of ecosystem assets within ecosystem types, flows of ecosystem services from those assets/types, and subsequent delivery of benefits to society into a set of *ecosystem accounts*. In an effort to achieve consistency and comparability nationally and internationally, ecosystem accounts should be aligned with the scope of accounting defined under the United Nation's System of Environmental Economic Accounts (SEEA) which provides an internationally accepted platform for compilation of environmental-economic accounts that are consistent and compatible with the United Nation's System of National Accounts (Australian Bureau of Statistics, 2021a; European Commission, International

Monetary Fund, Organisation for Economic Co-operation and Development, United Nations, & The World Bank, 2009). Tracking SEEA-compliant ecosystem accounts for a catchment, region or country through time should improve understanding of the contributions that ecosystem assets/types make to economic production and human wellbeing and help to elucidate the impacts of human activities on ecosystem assets/types and ecosystem service flows.

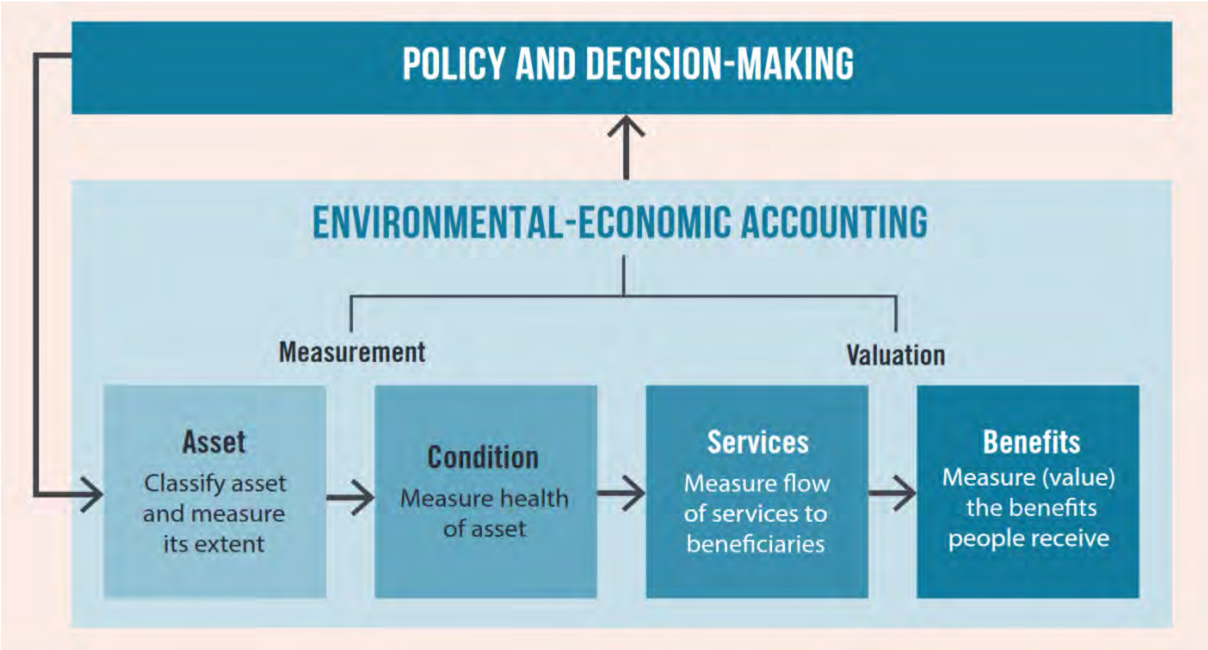


Figure 1. Components of environmental economic accounting linking to policy and decision-making. Source: Commonwealth of Australia (2018).

1.1 United Nations System of Environmental Economic Accounting

Over recent years, as demand for information on the condition of ecosystem assets and flows of ecosystem services has increased, there has been rapid growth in research on ecosystem service assessments and continuing developments in environmental-economic accounting (Guerry et al. 2015). However, thus far, this research, and the accounts developed from it, have had only limited impact on policy direction due to a lack of consistency across studies, with many studies using available data to compile accounts in formats that are highly location specific. There is a need for clear and consistent definitions of key terminologies and methodologies that can be applied to compile spatially scalable environmental-economic accounts (Balmford et al. 2002; Remme, Edens, Schröter, & Hein, 2015; Remme, Schröter, & Hein, 2014), and for replications of methodologically consistent and policy-relevant environmental-economic accounts from multiple geographic locations that conform with SEEA principles.

To encourage mainstreaming of environmental-economic accounting into national statistics, and after undergoing revisions, in March 2021, the United Nations Statistical Division (UNSD) released a SEEA Central Framework (United Nations, European Union, Food and Agriculture Organization of the United Nations, International Monetary Fund, et al. 2014) which provides an internationally standardised approach to recording information on:

- physical flows of natural resources (energy, water and materials) from the environment to the production economy
- physical flows of residuals (air emissions, water emissions and solid waste) from the economy back to the environment
- economic transactions that are considered environmental (activities related to environmental protection e.g., removal of weeds and pests; environmental taxes and subsidies)
- stocks and flows of individual environmental resources (mineral and energy resources, land, soil resources, timber resources, aquatic resources, other biological resources, and water resources) in physical and monetary terms
- valuation of stocks of environmental resources based on a net present value method.

The SEEA Central Framework (SEEA-CF) seeks to account for important inter-dependencies between stocks of renewable and non-renewable natural resources (e.g., minerals, energy resources, water, fish stocks) and the production economy. It provides an internationally standardised framework for tracking stocks of natural resources through time and for reporting – in biophysical terms (e.g., tonnes of ore extracted, gigalitres of water extracted) – flows of productive inputs from those stocks to sectors of the production economy (e.g., extractions from mineral deposits, extractions of irrigation water from water storages). SEEA-CF also reports flows of waste outputs (residuals) from the economy back to the environment, again in biophysical terms. SEEA-CF is designed to be compatible with standard national accounts such that SEEA-CF environmental-economic accounts can be seamlessly integrated into national accounts (Australian Bureau of Statistics, 2021a). Compatibility is ensured by using standard definitions for key terms and concepts that are consistent with the System of National Accounts (SNA) (Australian Bureau of Statistics, 2021a; European Commission et al. 2009). SEEA-CF's compatibility with SNA is what differentiates it from other environmental-economic accounting frameworks (e.g., Bateman *et al.* 2011; Costanza *et al.* 2014; Gopal, 2016). SEEA-CF provides a consistent and coherent approach for environmental-economic accounting that is readily integrated with socio-economic data to inform policy direction by governments or other stakeholders (United Nations, European Union, Food and Agriculture Organization of the United Nations, Organisation for Economic Co-operation and Development, et al. 2014).

SEEA-CF currently covers eight thematic areas (Agriculture, Forestry and Fisheries; Environmental Activity Accounts; Air Emissions Accounts; Material Flow Accounts; Energy; Water; Land Accounts; Ecosystem Accounts) in addition to one further area that is under development (Ocean) (Figure 2). Using the structures and principles laid out in SEEA-CF, each thematic area provides guidelines on compilation of accounts which integrate information on the environment and economic activities pertaining to that specific thematic area. To account for regulating and cultural ecosystem service flows, or the flow of provisioning ecosystem services as production inputs from ecosystem assets that are not defined as 'natural resource stocks', SEEA-CF is complemented by SEEA – Ecosystem Accounting (SEEA EA) (United Nations et al. 2021). Following global consultations, testing and revisions on the draft, SEEA EA was adopted by the United Nations Statistical Commission in March 2021 and further standardised in a White cover publication in September 2021 (United Nations et al. 2021). The final White cover version of SEEA EA (seea.un.org/ecosystem-accounting) provides the basis for compilation and development of ecosystem accounts for countries around the world.

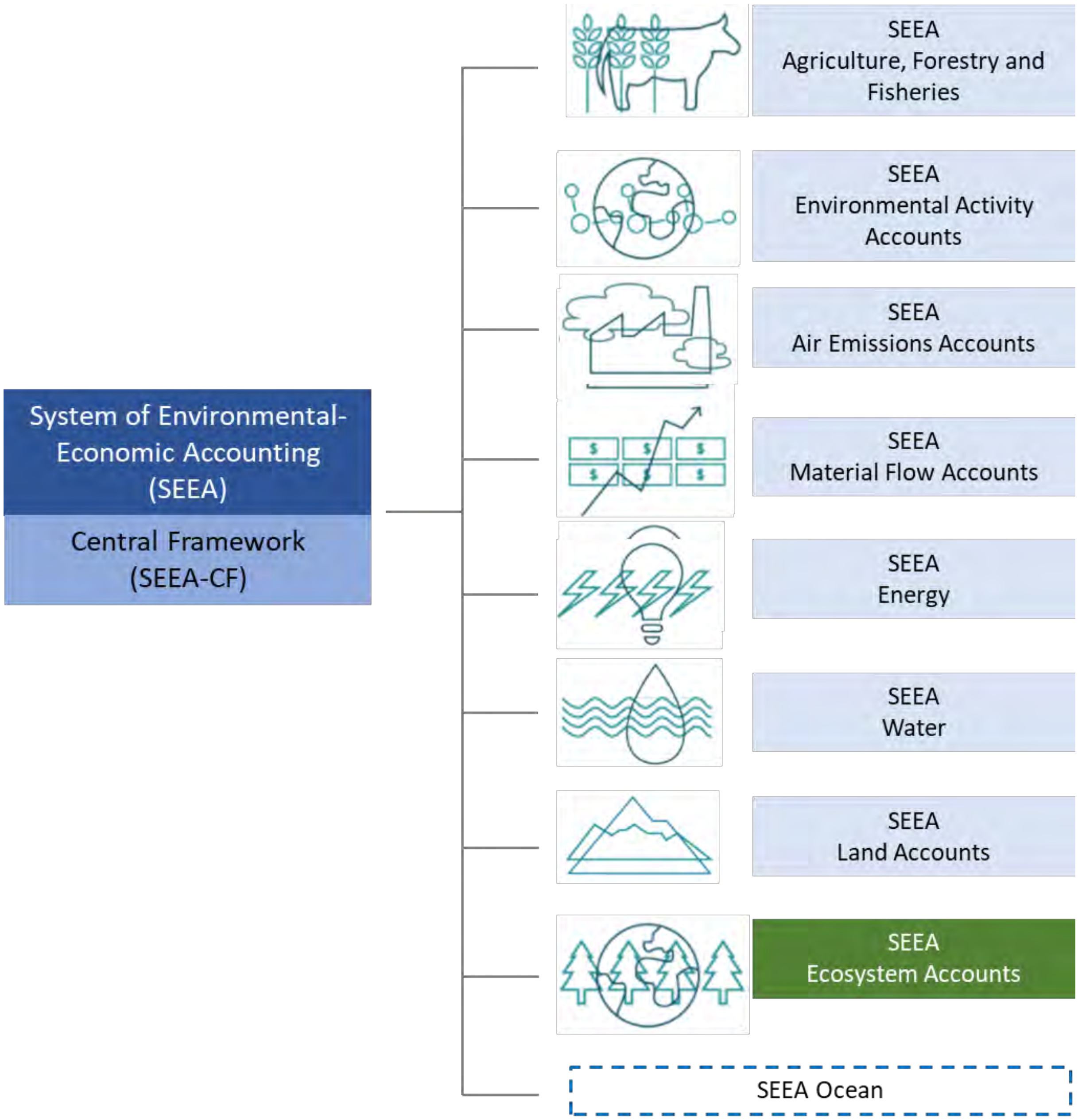


Figure 2. SEEA – Central Framework (SEEA-CF) and thematic areas. Source: seea.un.org accessed 16 June 2021.

Ecosystem accounting, as detailed in SEEA EA, is an accounting framework for integrating *spatially specific* socio-economic data with *spatially-specific* biophysical data on ecosystems and flows of ecosystem services. In contrast to SEEA-CF, and in similar vein to Australia's National Strategy and Action Plan for Environmental Economic Accounting (see Figure 1), SEEA EA views economy-environment interactions by starting from the perspective of ecosystem assets from which ecosystem services flow to the economy and thus contribute to generating material and non-material benefits to humans. Viewing the environment as a collection of ecosystem assets comprising different types of ecosystems (rather than a narrowly defined set of natural resource stocks) enables ecosystem accounting under SEEA EA to include regulating and cultural ecosystem services, together with flows of provisioning ecosystem services from ecosystem assets that are not regarded by SEEA-CF as 'natural resource stocks' (e.g., grazing fodder from the *pyric tussock savannas* ecosystem type on cattle stations). It is this wider dimension of ecosystem accounting that makes it attractive and relevant for informing land management policies to sustain the delivery of a broader suite of valuable ecosystem services into the future.

The SEEA EA framework defines a methodology for producing a set of interlinked ***ecosystem accounts*** that classify ecosystem assets into ecosystem types, report on extent and condition of the assets within each ecosystem type, and report on flows of ecosystem services from these assets, grouped into ecosystem types, (in biophysical terms), together with the value of the contributions to benefits these services provide to humans (in monetary terms).

Figure 3 (adapted from Lai et al. (2018); Figure 1, p.53) shows the set of physical and monetary ecosystem accounts in the SEEA EA framework and indicates how they can be interfaced with SNA accounts. Biophysical ecosystem asset accounts are compiled first; these consist of an ***ecosystem extent account*** and an ***ecosystem condition account***. Individual ecosystem assets (individual patches of wetland, woodland, grassland etc.) are grouped by ecosystem type in the extent and condition accounts. Ecosystem types are ecologically distinct types of wetland, woodland, grassland etc., with ecosystem classifications following the IUCN's Global Ecosystem Typology (D. A. Keith, Ferrer-Paris, Nicholson, & Kingsford, 2020).

Flows of ecosystem services from ecosystem assets, again grouped by ecosystem type, are compiled into an ***ecosystem service supply and use account in biophysical terms***. The supply and use of ecosystem services is then valued using appropriate exchange value-equivalent prices to produce an ***ecosystem service supply and use account in monetary terms***. *Supply* of ecosystem services in biophysical and monetary terms *is reported by ecosystem type* in biophysical and monetary accounts. *Use* of ecosystem services *is reported by category of economic unit: industries, households and governments*. Monetary supply and use accounts for ecosystem services can be integrated with the SNA's extended supply and use accounts that report flows of value within a given time period (quarter or year) (Australian Bureau of Statistics, 2021a). A final step in compilation of the full suite of SEEA Ecosystem Accounts – the step that is the most challenging in terms of information requirement – would entail compilation of an ***ecosystem asset value account in monetary terms***. The ecosystem asset value account would aim to provide a monetary valuation of ecosystem assets (again grouped by ecosystem type), *based on the total net present value of the flow of ecosystem services provided by all assets within an ecosystem type over a defined time horizon*. If the ecosystem asset value account is to be suitable for subsequent integration into SNA's balance sheets it should include: (i) estimates of the capacity of ecosystem assets to provide a relevant suite of ecosystem services over a defined future time horizon, (ii) information on patterns of future consumption of services, (iii) information on current and future asset management, and (iv) assumptions on discount rate and the chosen time horizon. It is the requirement to assemble this (considerable) suite of additional information that makes it particularly challenging to produce an ecosystem asset value account in monetary terms.

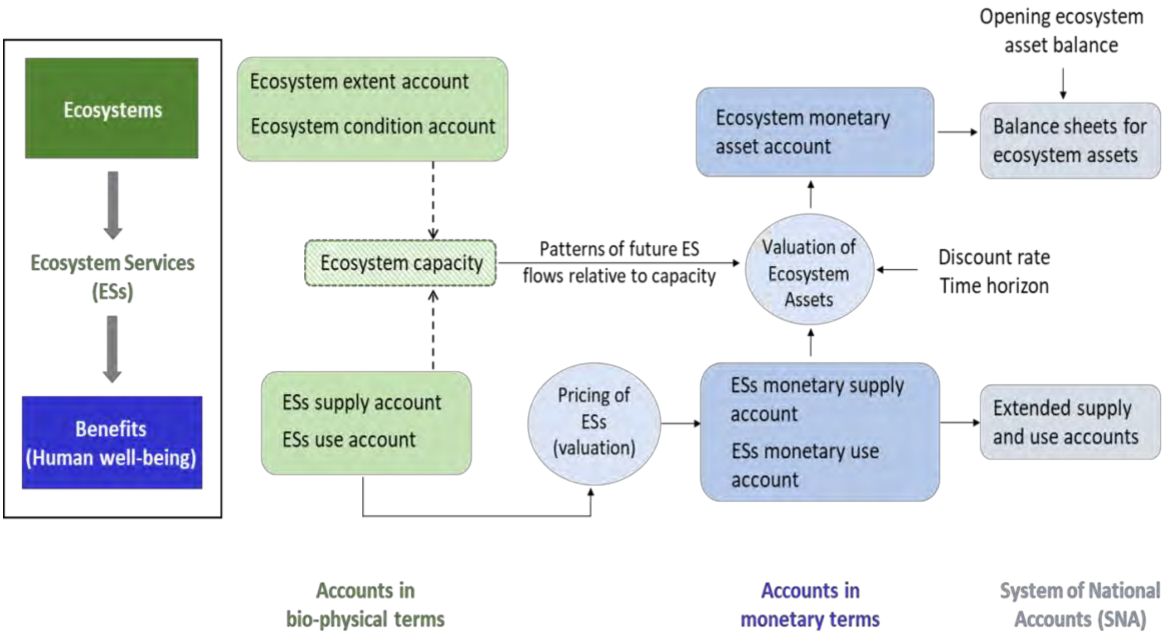


Figure 3. Biophysical and monetary ecosystem accounts within the SEEA EA framework, showing links to the System of National Accounts (SNA). Adapted from Lai et al. (2018); Figure 1, p.53.

The overarching objective of NESP Northern Australia Environmental Resources Hub Project 4.6 is to produce a pilot set of SEEA EA-compliant ecosystem accounts for the Mitchell River catchment in far north Queensland. Specifically, Project 4.6 has produced the following ecosystem accounts (as accounting tables supported by relevant maps) for the Mitchell catchment:

- ecosystem extent account
- ecosystem condition variable account and supplementary environmental pressures
- ecosystem service biophysical supply and use account
- ecosystem service monetary supply and use account.

Project 4.6 also explores methodologies for addressing several complexities that have limited the scope of SEEA EA-compliant ecosystem accounts hitherto. Thus, in addition to these four ecosystem accounts, data on environmental pressures, land uses and other supporting information that may be useful for informing land management policy has also been collated through this project. These Supplementary Accounts combine information on land uses and anthropogenic pressures on the extent and condition of ecosystem assets, where pressures can be regarded as surrogate indicators of ecosystem condition informed by existing management frameworks. A key advantage of augmenting the Mitchell's Ecosystem Accounts with Supplementary Information on pressures that has been collected for land management purposes is that this information is likely to be updated regularly by relevant bodies as part of on-going performance monitoring.

Further details of the objectives of Project 4.6 are provided in Section 1.9 below. Sections immediately below provides a brief introductory description of the Mitchell catchment.

1.2 The Mitchell catchment

For tens of thousands of years prior to European invasion and settlement, the ancestors of today's Traditional Owners of the Mitchell catchment socialised the landscapes of the region as they managed land and water, fulfilled custodial responsibilities under customary law and maintained an economic system that sustained their way of life. This active management by Traditional Owners continues in many localities today, albeit under constrained conditions.

The Mitchell catchment is one of the 245 catchments (National Catchment Boundary Level 2) in Australia (Stein, Hutchinson, & Stein, 2011). The catchment is situated in the tropical north-eastern part of the country within the state of Queensland and covers an area of approximately 71,720 km^2 or 0.93% and 4.15% of Australia's and Queensland's total land area, respectively (Geoscience Australia, n.d.). The catchment system consists of five main rivers, the Alice, Palmer, Mitchell, Walsh and Lynd, flowing from the Great Dividing Range in the east and discharging into the Gulf of Carpentaria in the west (Figure 4).

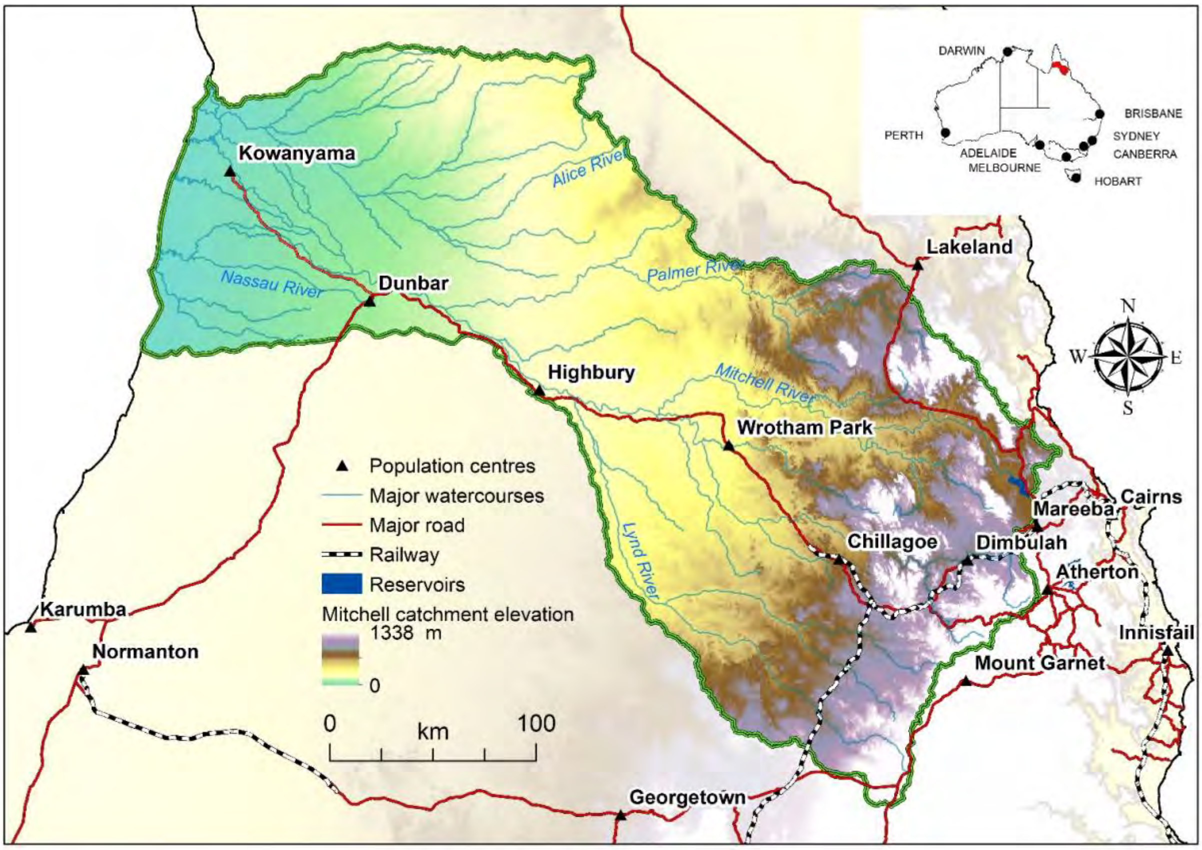


Figure 4. Topographical map of the Mitchell River catchment in Far North Queensland showing the main rivers, reservoirs, major roads and railways. The inset map shows the Mitchell River catchment within Australia.

The Mitchell catchment contains three wetland areas of national significance (the Mitchell River Fan aggregation (in the Mitchell delta), the South-East Karumba Plain aggregation (located along the coastal plain and the delta), and the Spring Tower complex (in the upper Lynd subcatchment). These wetlands contribute to the catchment's high aquatic biodiversity, with the Mitchell catchment having the second highest richness of fish species diversity in Australia (Pollino et al. 2018).

The catchment spans seven local government areas of which four (Mareeba Shire, Cook Shire, Carpentaria Shire and Kowanyama Aboriginal Shire) cover 99.3% of the catchment. The majority of the catchment area is served by Mareeba Shire Council and Cook Shire Council at 51% and 27% of the catchment area, respectively. The Kowanyama Aboriginal Shire Council covers an area of 2,523 km^2 of which 91% is in the Mitchell catchment.

1.3 Ecosystem management in the Mitchell catchment: context

The development of environmental-economic accounts faces many challenges that are noted in the ecological economics literature and elsewhere (e.g., Hein et al. 2020, 2015; Keith et al. 2021). One of the problems that is given relatively little attention in this literature – at least from the perspective that we are about to discuss here – arises from a requirement to select a baseline against which changes in ecological condition can be tracked in SEEA Ecosystem Accounts. The Wentworth Group term this a 'reference benchmark' which they define as 'a scientific estimate of an environmental asset in its undegraded (natural, pre-industrial or potential) state' (Wentworth Group of Concerned Scientists, 2016; p.11). Working within the ecosystem health literature, and referring back to IUCN UNEP WWF (1991) and Vitousek et al. (1986), Chapman (1992) suggested the year 1750 as a date from which the extent of human impact on ecosystem condition could be assessed (Chapman, 1992; Fig. 2 p.75). Chapman suggested that ecosystems could be categorised as being in 'natural condition' if the extent of human impact on ecosystem condition since 1750 did not exceed that of any other species, and if human impact had not affected the structure of the ecosystem. Conversely, if human impact since 1750 exceeded that of any other species – but not to the extent that the original ecosystem had been converted for cultivation purposes – then the ecosystem could be categorised as being in 'modified condition'.

In settler colonial contexts like Australia there has been a long-standing tendency of environmental scientists and others to assume the pre-colonial 'natural' state of the environment as the baseline for evaluating environmental change and to conflate colonial impacts with development trajectories. This tendency is reflected in the fact that Australian environmental accounting studies often use a 'pre-European settlement' date of 1750 for this reference benchmark condition (Wentworth Group of Concerned Scientists, 2016 – citing Norris and Thoms (1999)).

Environmental accounts that uncritically adopt such a benchmark run the risk of erasing Indigenous occupation and systems of governance and management, as well as misrepresenting the environmental change Indigenous and settler forms of land management have effected. The Mitchell catchment has been appropriated and occupied by settlers, but for tens of thousands of years prior, the ancestors of today's Traditional Owners of the Mitchell catchment socialised the landscapes of the region as they managed land and water, fulfilled custodial responsibilities under customary law and maintained an economic arrangement that sustained their way of life (Barber, Jackson, Shellberg & Sinnamon, 2014; Jackson & Palmer, 2015; Strang, 2000).

The analogous term to the Wentworth Group's 'reference benchmark'' in the September 2021 SEEA EA White cover version is 'reference condition', which is defined as follows:

> 'The reference condition of an ecosystem corresponds to the condition where the structure, composition and function are dominated by natural ecological and evolutionary processes including food chains, species populations, nutrient and

> hydrological cycles, self-regeneration and involving dynamic equilibria in response to natural disturbance regimes. An ecosystem at a natural reference condition exhibits an absence of major human modification. An ecosystem at its reference condition attains maximum ecological integrity'. (United Nations et al. 2021; paragraph 5.70, p.97).

However, the SEEA EA White cover version is somewhat flexible in recognising that different forms of reference condition may be appropriate for 'natural' and 'anthropogenic' ecosystems (United Nations et al. 2021; Annex 5.2, paragraph 5.1 and Table 5.8, p.115) – and it recognises that an appropriate reference condition could be a 'historical condition' which:

> '[indicates] The condition of an ecosystem at some point or period in its history that is considered to represent the stable socio-ecological state (e.g., the pre-industrial period or pre-intensive agriculture)' (United Nations et al. 2021; Annex 5.2, Table 5.8, p.115).

This historically anchored definition of a reference condition for ecosystems in the Mitchell catchment can acknowledge that the ancestors of today's Traditional Owners managed land and water, fulfilled custodial responsibilities under customary law and maintained an economic arrangement that sustained their way of life as described above, resulting in socialised landscapes that were stable in socio-ecological terms.

Adopting estimated conditions of the ecosystems in the Mitchell catchment as socialised landscapes under Traditional Ownership prior to settler appropriation as 'reference conditions' in our SEEA EA for the Mitchell is also consistent with use of 'pre-clearing' as the reference condition for the Queensland Herbarium's Broad Vegetation Groups and Regional Ecosystems across the state (Queensland Herbarium, 2021a). We use the Queensland Herbarium's ecosystem designations and mapping layers to produce spatial representations of ecosystems in the Mitchell in our SEEA Ecosystem Accounts. Consequently, throughout this report we use the term 'pre-clearing' to refer to the historical reference condition for the ecosystems in our Ecosystem Accounts for the Mitchell Catchment, as we consider that this definition respectfully acknowledges that 'pre-clearing', the land and water ecosystems in the Mitchell catchment were actively managed as socialised landscapes by the ancestors of today's Traditional Owners in fulfilment of their custodial responsibilities.

1.4 The lower Mitchell catchment, the Mitchell delta and Kowanyama

As Project 4.6 had a limited budget for fieldwork, it was decided that on-ground research to investigate how changes in ecosystem condition affected supply of provisioning, regulating and cultural ecosystem services from an Indigenous perspective, and associated research to investigate whether mechanisms could be developed to produce meaningful SEEA EA-compliant valuations of cultural ecosystem services that are relevant for First Nations residents, would focus on a single section of the Mitchell catchment. The lower Mitchell catchment and the Mitchell delta, centred on the township of Kowanyama, was chosen as the location for this research (Figure 5). This decision was taken because Project 4.6 researchers had collaborated successfully with the local, predominantly Indigenous, community in Kowanyama previously. With the support of Kowanyama Aboriginal Land and Natural Resource Management Office, Abm Elgoring Ambung RNTBC, and Kowanyama Aboriginal Council, Project 4.6 research associate Viv Sinnamon – a longstanding Kowanyama resident and collaborator – collected data and information about the ways in which Traditional Owners care for Country in the lower Mitchell catchment and delta and how their ability to conduct multiple on-Country activities has been impacted by the increasing presence and prevalence of feral animals and invasive weeds. These data were collected in accordance with Griffith University Human Research Ethics Approval No. 2019/850.

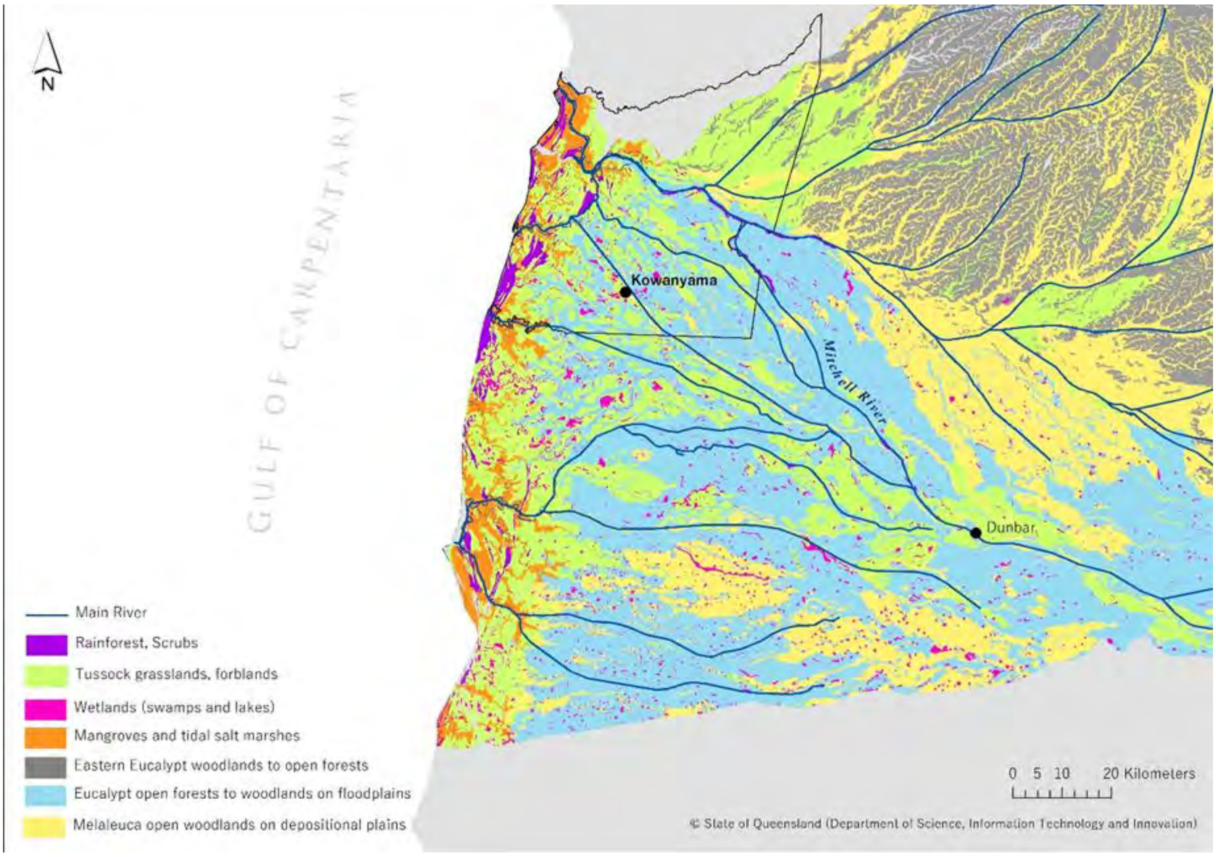


Figure 5. Location of Kowanyama in the lower Mitchell River catchment, showing ecosystem types in the locality.

The predominantly Indigenous community of Kowanyama contains three language groups: the Yir Yoront, the Kokobera, and the Kunjen people (Strang, 2000). Prior to colonisation, many of the clans in these groups lived on traditional land now in neighbouring cattle stations and in the Alice-Mitchell Rivers National Park to the north-east of Kowanyama (Strang, 2000). The 2016 census for Kowanyama encompassed a population of 944 persons of whom 856 (91%) were Indigenous (Australian Bureau of Statistics, n.d.). The majority are direct descendants of the Indigenous inhabitants of the lower Mitchell and Alice Rivers, and neighbouring areas now held by pastoral tenants (Sinnamon, O'Brien, & Kerr, 2008). They include the three linguistically defined groups reported by Strang (2000), with traditional links to Country along the Mitchell River, and in adjacent lands as far south as the Staaten and Nassau Rivers.

> 'The Mitchell River Delta in northern Australia is the ancestral and current home of the Kokoberra, Kokoberrin, Yir Yoront, Yir Thangedl, and Kunjen Aboriginal People. They have managed and been supported by the Delta's freshwater wetlands and coastal waters of the Gulf of Carpentaria for thousands of years. Today, 1000 Aboriginal

People from these linguistic groups live in the community of Kowanyama with strong connections to Homelands across the Delta and beyond.' (Shellberg et al. 2017: p.vi)

The Mitchell River landscape is anything but an empty, inert wilderness, as Strang explains in the following quote:

> '… ancestral tracks … reflect a cosmological vision of the land as having been created by ancestral beings in the 'Dreamtime', or 'Story Time' as it is called in North Queensland. Having acted upon and formed the landscape, the ancestral beings went back into the land, bequeathing it to totemic clans in perpetuity, and conferring upon them inalienable rights of ownership and responsibility for caring for its well-being. They remained in the land 'for all time', creating a sentient landscape which watches and responds to human action.'
>
> 'The male and female ancestral forces within the land are generative, providing wells of human spirituality which tie each individual to a spiritual conception site on or near their clan land. Human cycles of birth, growth and death are further bound into the land by a series of ceremonial interactions reaffirming these 'ancestral connections' … The clan's own land is said to 'give' resources to it, for example allowing people to catch fish, or find what they need, whilst withholding these from strangers. The relationship is presented as reciprocal: clans take care of their land through managing it properly, keeping it 'clean', and through ritual activities which manifest the presence of the ancestral beings; the land 'knows' and takes care of them by providing resources and refraining from being malevolent towards them.' (Strang, 2000; p.282)

The system of land and natural resource management practised by Aboriginal clans of this region was severely disrupted by colonisation, particularly the removal of people from their homelands, the establishment of missions and reserves, and the introduction of pastoralism and mining. In addition to bringing about great social change, these land uses affected the condition of the catchment (Brooks et al. 2009; Shellberg et al. 2016 – and examples of adverse consequences from invasive weeds and feral animals cited later in this report). Yet, Aboriginal people continued to hunt and gather and to maintain connections with and manage their land as best they could alongside these introduced modes of production (Strang, 2000). Barber et al. (2014) reveal the significance of consistent Indigenous residence to ecological management of some of the former pastoral lands and describe how Aboriginal stockmen of the region were able to retain and adapt their knowledge as they worked pastoral leases.

Following concerns over expanding European settlement and associated impacts on local Aboriginal communities, the Queensland Government declared the Mitchell River an Aboriginal Reserve for the Benefit of Aboriginals of the State in 1903 (Sinnamon et al. 2008). In 1905, the Anglican Church established a Mission Station at Trubanamen, near Topsy Creek, which today marks the southern boundary of the Kowanyama Aboriginal Trust Lands. The Queensland Government took over the administration of the Reserve in 1967 but later transferred Aboriginal Reserve Lands and administrative control back to the people as Deeds of Grant in Trust, then represented by the newly established Kowanyama Aboriginal Council in 1987 and empowered through national legislation in support of Aboriginal self-governance.

The community now living in Kowanyama has primary claims to several thousand square kilometres of land within and surrounding their 'Deed of Grant in Trust' area now held as Aboriginal Freehold Lands by the Prescribed Body Corporate (NT), Abm Elgoring Ambung since their successful Native Title Claim (*The Kowanyama People*) in 2009. Aboriginal Freehold title to the area being granted in 2013. Kowanyama Aboriginal landholdings include the Mitchell River delta and the lower reaches of the Alice River (Sinnamon et al. 2008). The landholdings occupy approximately 4,120 km^2, encompassing the Aboriginal Land Trust and two pastoral properties, Helmsley (Oriners) and Sefton, purchased by the Kowanyama Aboriginal Council in the 1990s, land over which native title is now recognised[5] (Figure 6). The 1990s saw the establishment of homelands or outstations outside Kowanyama by kin groups and their families who were able to maintain connections with ancestral estates from these bases.

In response to concerns over mining and fisheries development, the Kowanyama Aboriginal Council established the Kowanyama Aboriginal Land and Natural Resources Management Office (KALNRMO) in 1990. The KALNRMO functions as a department of the elected Kowanyama Aboriginal Council, which together with the Traditional Landowners represented by Abm Elgoring Ambung (Prescribed body Corporate NT), holds the decision-making authority for this Country. The strategic role of the Land Office is therefore one of implementation, as it aims 'to achieve sustainable Aboriginal management of the natural and cultural resources of Kowanyama land and sea Country, given that the continuing cultural and biological diversity of Country are integrally linked and cannot be viewed as separable' (Sinnamon et al. 2008).

The Land Office continues to be a recognised community authority on natural resource management issues, and is home to an Indigenous ranger group, based in Kowanyama. The KALNRMO will be involved in ongoing discussions with Abm Elgoring Ambung on the future management of land under different tenure regimes (Aboriginal Feehold, pastoral lease, National Park, etc.) with a diverse array of near neighbours, particularly other Indigenous landholders and non-Indigenous pastoral leaseholders. Kowanyama is situated at the downstream end of the Mitchell River. Kowanyama has been involved for decades in sometimes complex local relationships with near neighbours, and with multiple levels of governance and government – local, catchment, Cape, State, and national. Research by Barber (2015) found that the KALNRMO had:

- acted as a role model for many, much newer Indigenous land management organisations
- positively influenced the attitudes to ICNRM held by local pastoralists and catchment managers
- influenced generations of researchers.

Kowanyama is engaged in the development of an updated regime of land management as adjustments are made to the new roles adopted for service delivery with the changing responsibilities under the Native Title Act and Prescribed Body Corporates whose role will lie in representing the interests of Traditional Owner Groups.

[5] Oriners and Sefton are both part of the Cape York United #1 Claim for which determination is expected in July 2022 (www.cylc.org.au).

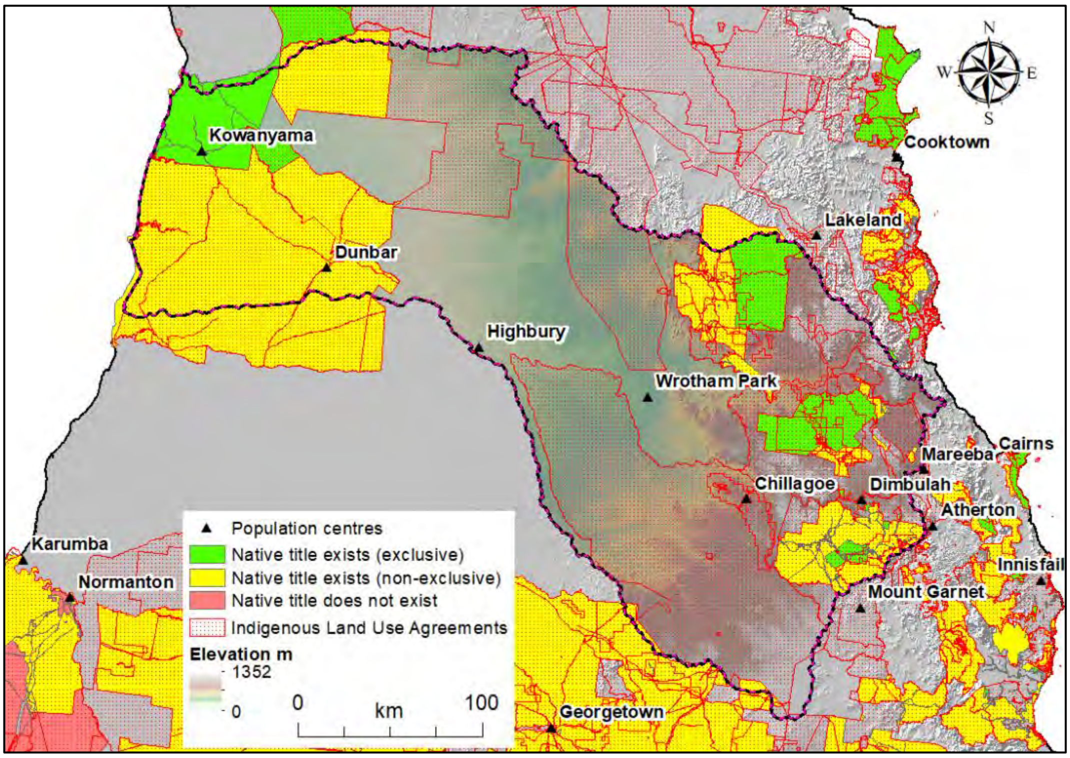


Figure 6. Map of the Mitchell River catchment showing areas designated under Indigenous Native Titles (both exclusive and non-exclusive) and Indigenous Land Use Agreements. Note that this map pre-dates the Cape York United #1 Claim over pastoral land on Helmsley (Oriners) and Sefton stations. Source: Geospatial Data Model, National Native Title Tribunal, Version 2.1 October 2020.

1.5 Climate and rainfall patterns

Rainfall in the Mitchell catchment is predominantly from the summer monsoon, with the majority of rain falling between November and April (Charles et al. 2016). On average, the catchment experiences at least one tropical cyclone in 75% of years (CSIRO, 2018). The remainder of the year is usually dry, particularly in more southerly sub-catchments such as the Lynd. Mean average rainfall for the catchment over the period 1890 to 2015 was 996 mm (Charles et al. 2016). Inter-annual variability in rainfall is high, with rainfall totals in the Mitchell catchment being 1.3 times more variable year to year than in comparable areas elsewhere in the world (CSIRO, 2018). Consequently, flows down the Mitchell main channel and its tributaries vary substantially between the wet and dry seasons, and between years (Figure 7). These strong seasonal and inter-annual variations in flow drive corresponding changes in the connectivity and productivity of aquatic ecosystem assets, with likely consequences for the ecosystem services these assets supply (Pollino et al. 2018).

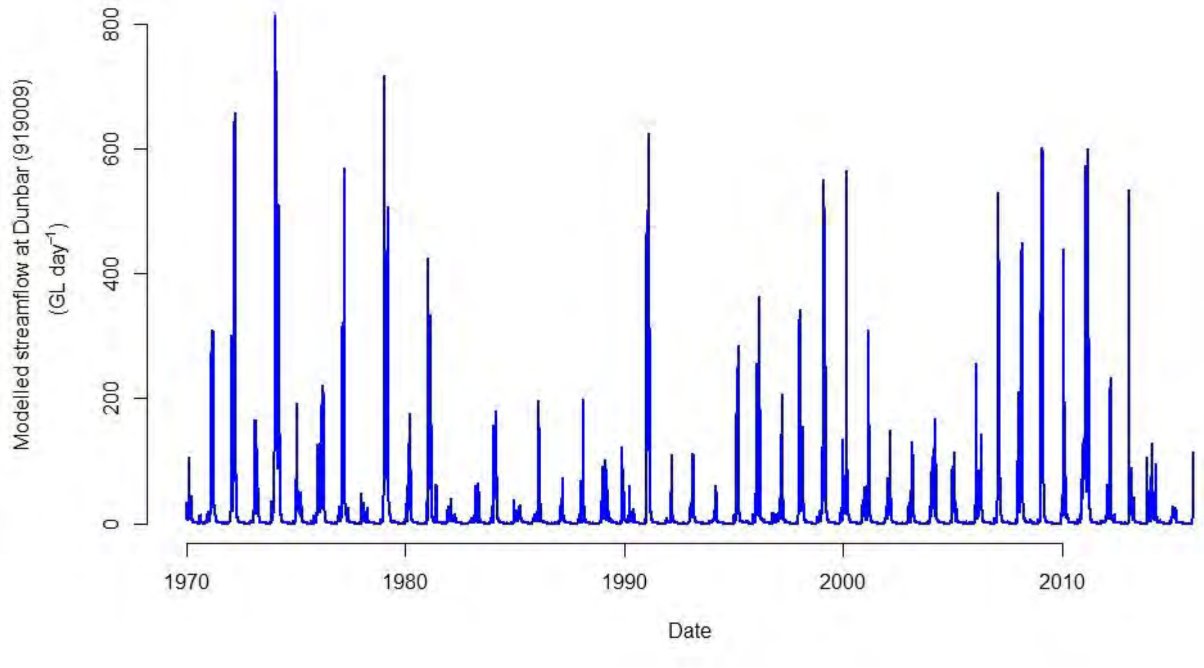


Figure 7. Modelled streamflow at Dunbar (919009), at the head of the Mitchell delta fan. Data from CSIRO streamflow modelling (Hughes et al. 2017).

1.6 Land use

Land use maps for the state of Queensland are produced by the Queensland Government's Department of Environment and Science under the Queensland Land Use Mapping Program (QLUMP) (Queensland Government, 2019). Land use datasets from QLUMP are derived from the Australian Land Use and Management (ALUM) Classification that is maintained by Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) within the Australian Government Department of Agriculture, Water and the Environment (DAWE). The ALUM Classification follows a three-tiered hierarchical structure of primary (Class 1), secondary (Class 2) and tertiary (Class 3) classes. The primary and secondary classes relate to land use and the tertiary class includes information on commodity groups, specific commodities, land management practices or vegetation information (ABARES, 2016). As QLUMP is based on ALUM Classifications, all land use datasets published by QLUMP are nationally consistent.

For the Mitchell catchment, QLUMP spatial layers are available for the years 1999 and 2015. ALUM Classification Version 8 was applied in the QLUMP mapping for some parts of Queensland, however, this has yet to be expanded to the Mitchell catchment. Thus, the older version of ALUM, Version 7, was used as the basis of the QLUMP spatial dataset that was available from the outset of Project 4.6 for the Mitchell catchment. Land use maps at primary and secondary classes in 2015 for the Mitchell catchment are shown in Figure 8 and Figure 9, respectively. The *production from relatively natural environments* QLUMP primary class covered just over 80% of the catchment, followed by *conservation and natural environments* at 15% of the land area (Figure 8). Further breakdown of the *production from relatively natural environments* primary class into secondary classes of *grazing native vegetation* and *production forestry* showed that grazing native vegetation comprised 99% of the area of the primary class, at 57,337 km^2 (Figure 9). Figure 10 provides a summary of primary and secondary classes for all land uses in the Mitchell catchment in 2015.

As indicated by the QLUMP data, the majority of land area in the Mitchell catchment is currently used for open range cattle rearing on large grazing leases, with cattle grazing on native vegetation on unimproved land (Ash et al. 2018; Stokes et al. 2017). Low rates of biomass growth due to low annual rainfall and low soil fertility typically preclude cattle fattening, so most cattle stations in the Mitchell operate cattle breeding operations that sell young animals on for fattening elsewhere (Ash et al. 2018). Cattle stations in the catchment have low cattle carrying capacity at approximately 1 adult equivalent (AE) (McLennan, McLean, & Paton, 2020) per 10 to 20 ha, and total number of cattle is estimated at approximately 185,000 heads (Lyons et al. 2018; p.107). Typically, weaners (120–160 kg) or yearling animals (250–350 kg) are either sold to other beef production businesses further south in the state or exported live to Asia (Lyons et al. 2018; p.107).

Irrigated cropping of mangoes, bananas, avocados, sugarcane, irrigated pastures and a range of other seasonal and perennial horticulture crops (i.e., categorised as the *production from irrigated agriculture and plantations* QLUMP primary class) is practiced on around 225 km^2 of land in the catchment (0.31% of the catchment area). Most of the irrigated cropping area is supplied from the Mareeba Dimbulah Water Supply Scheme (MDWSS) in the headwaters of the Walsh River in the extreme east of the Mitchell catchment. The MDWSS draws its water from Lake Tinaroo in the neighbouring Barron catchment. This water, a valuable provisioning ecosystem service input to irrigated agriculture, is thus not sourced from within the Mitchell catchment itself, although it is used within the Mitchell – and is therefore is included in the Ecosystem Accounts for the catchment (but this service is listed as an ‘Import’ in the supply and use tables because it is not supplied by ecosystems within the Mitchell catchment itself).

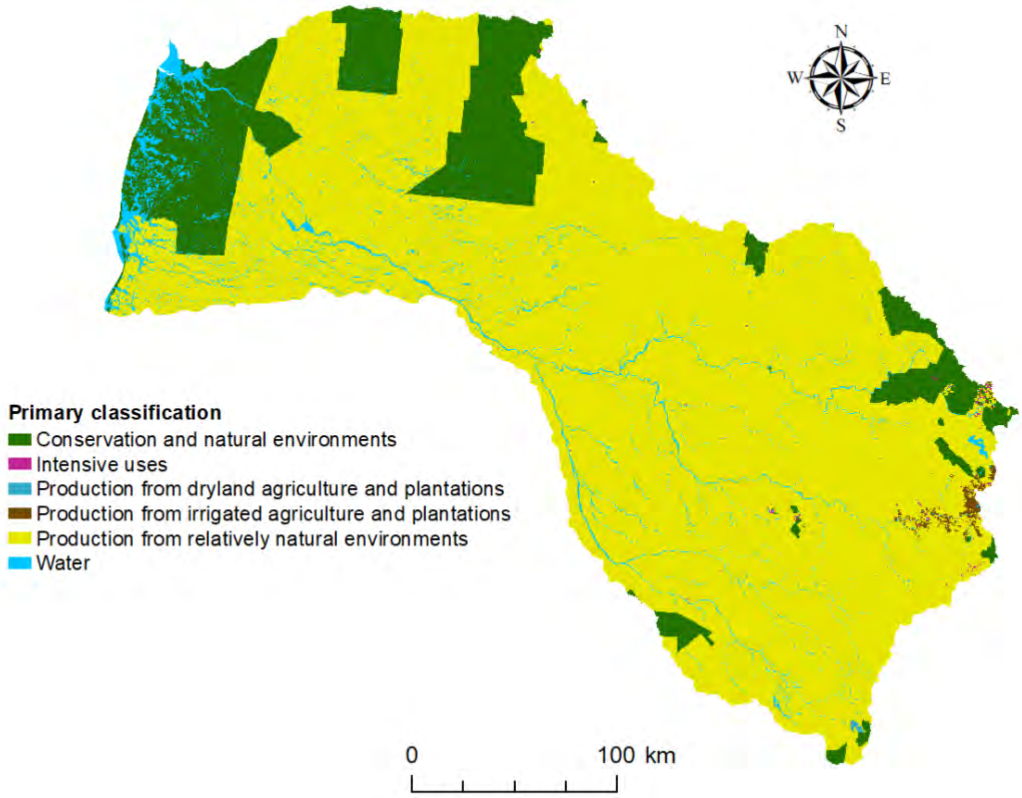


Figure 8. Mitchell catchment land use map for 2015, classified into six primary classes as per ALUM Classification Version 7 (May 2010).

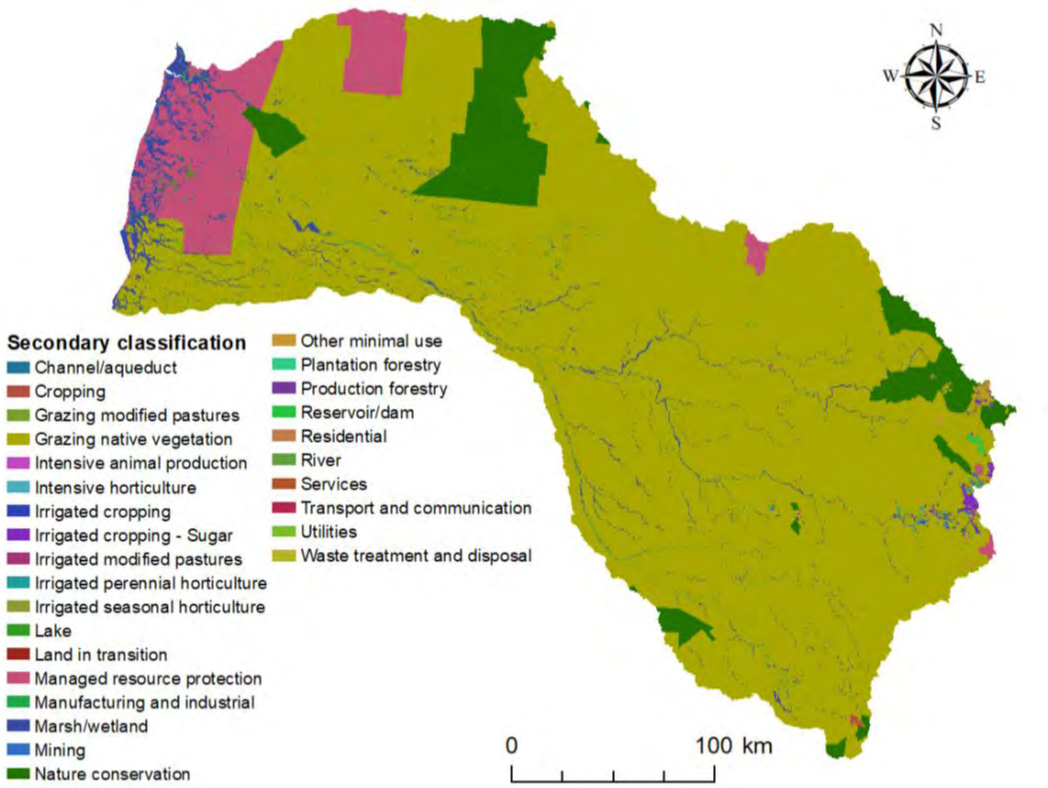


Figure 9. Mitchell catchment land use map for 2015, classified into 28 secondary classes as per QLUMP (Queensland Government, 2019).

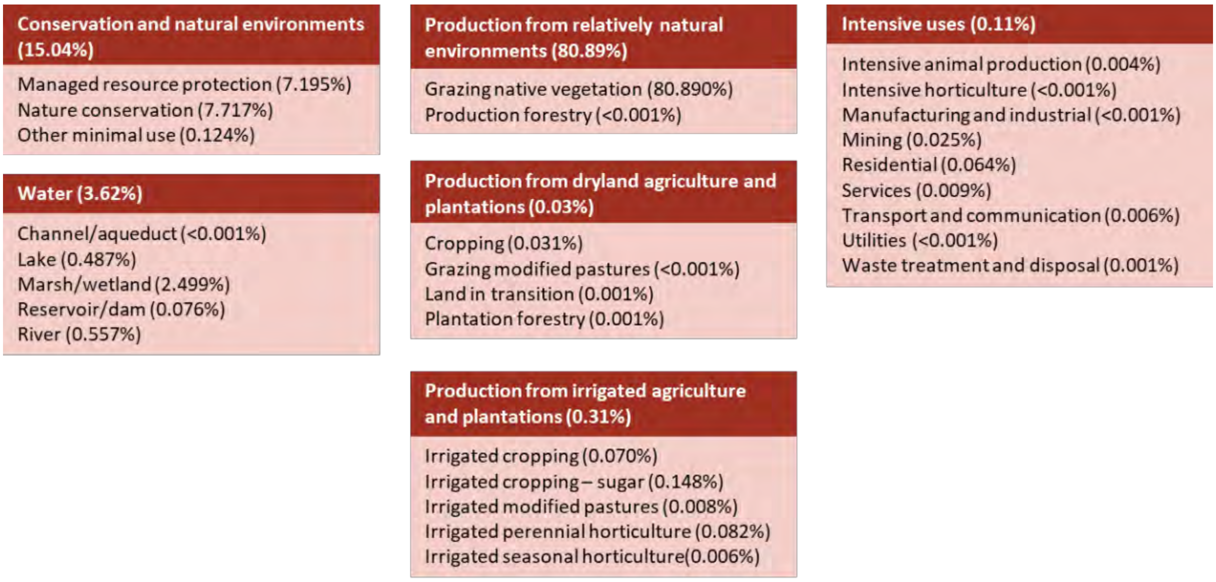


Figure 10. Land use in the Mitchell catchment as mapped in QLUMP. This QLUMP dataset, published by the Queensland Department of Environment and Science (Queensland Government, 2019), is based on ALUM Classification version 7. ALUM Classification Version 8 was applied in the QLUMP mapping for other parts of Queensland, but it is not yet available for the Mitchell catchment at the time of writing. Numbers in brackets indicate the area as a percentage of the Mitchell catchment.

1.7 Economy

Agriculture, fisheries, tourism and mining are all major contributors to the economy of the Mitchell catchment (Lyons et al. 2018). However, mining within the Mitchell makes a negligible contribution to Queensland's mining revenue; furthermore, subsurface mineral deposits are not included in SEEA Ecosystem Accounts, and consequently they are not considered further in this report. Whilst the Mitchell catchment falls within Tropical North Queensland, a tourism hotspot, most tourism activity will be concentrated along the eastern coastline for which the Great Barrier Reef is the main drawcard. By comparison, the Mitchell catchment, beyond the Tablelands, is relatively remote and inaccessible. Tourist visitation data are available for parts of the Mitchell catchment at local government area (LGA) resolution. These data are used as described subsequently in Sections 7.8.1 and 8.4.1, to estimate supply of recreation-related ecosystem services from ecosystems in the catchment in biophysical and monetary terms.

The agricultural sector is the largest contributor to the economy of the Mitchell catchment, producing approximately $284 million worth of livestock, fruit, vegetables and broadacre crops in 2015–16 (Data Farm | Department of Agriculture and Fisheries, Queensland (daf.qld.gov.au)). A State of Queensland-administered commercial inshore gillnet barramundi fishery operates in the Mitchell estuary and within the immediate coastal zone, as a sub-component of the Gulf of Carpentaria Inshore Fin Fish Fishery (GoCIFFF) (State of Queensland Department of Agriculture and Fisheries, 2019a). Vessels of Commonwealth-administered Northern Prawn Fishery catch white banana prawns that originated from the Mitchell further offshore in the Gulf of Carpentaria (afma.gov.au/fisheries/northern-prawn-fishery). However, as SEEA EA assigns supply of ecosystem services to the ecosystem in which that service delivers its contribution to value – i.e., for fisheries, the ecosystem in which the harvested catch is taken – barramundi caught by the inshore gillnet fishery *are* included in the Ecosystem Accounts for the Mitchell, but banana prawns caught out in the Gulf by the Northern Prawn Fishery *are not*.

1.8 Demographic and socio-economic statistics

According to the 2016 census (Australian Bureau of Statistics, 2017), the Mitchell River catchment has a low population density ranging between 0 people per km^2 (98.7% of the catchment area) and 588 people per km^2 (Figure 11). In total, 15 Australian Bureau of Statistics (ABS) State Suburbs in the Mitchell catchment contain almost all of the resident population of 6,048 (Figure 12a and b). State Suburbs (SSCs) are an ABS approximation of Gazetted Localities that are created to improve the accuracy of ABS data representation at a spatial scale that aligns with official boundaries of suburbs and localities. These boundaries are different to the previous State Suburbs defined using whole of SA1s (Australian Bureau of Statistics, 2016). The largest SSC by population size with part of its land area in the catchment is Mareeba (population 11,079); however, only a small proportion of the area of the Mareeba SSC actually falls within the Mitchell. The most heavily populated SSCs that fall either entirely or substantially within the Mitchell catchment are Julatten, Dimbulah, Arriga and Kowanyama, all of which have a population of around 1,000. Other SSCs such as Chillagoe, Almaden, Irvinebank, Lakeland, Watsonville, Mount Carbine and Mount Molloy had considerably smaller populations (less than 300) at the 2016 census (Australian Bureau of Statistics, 2017).

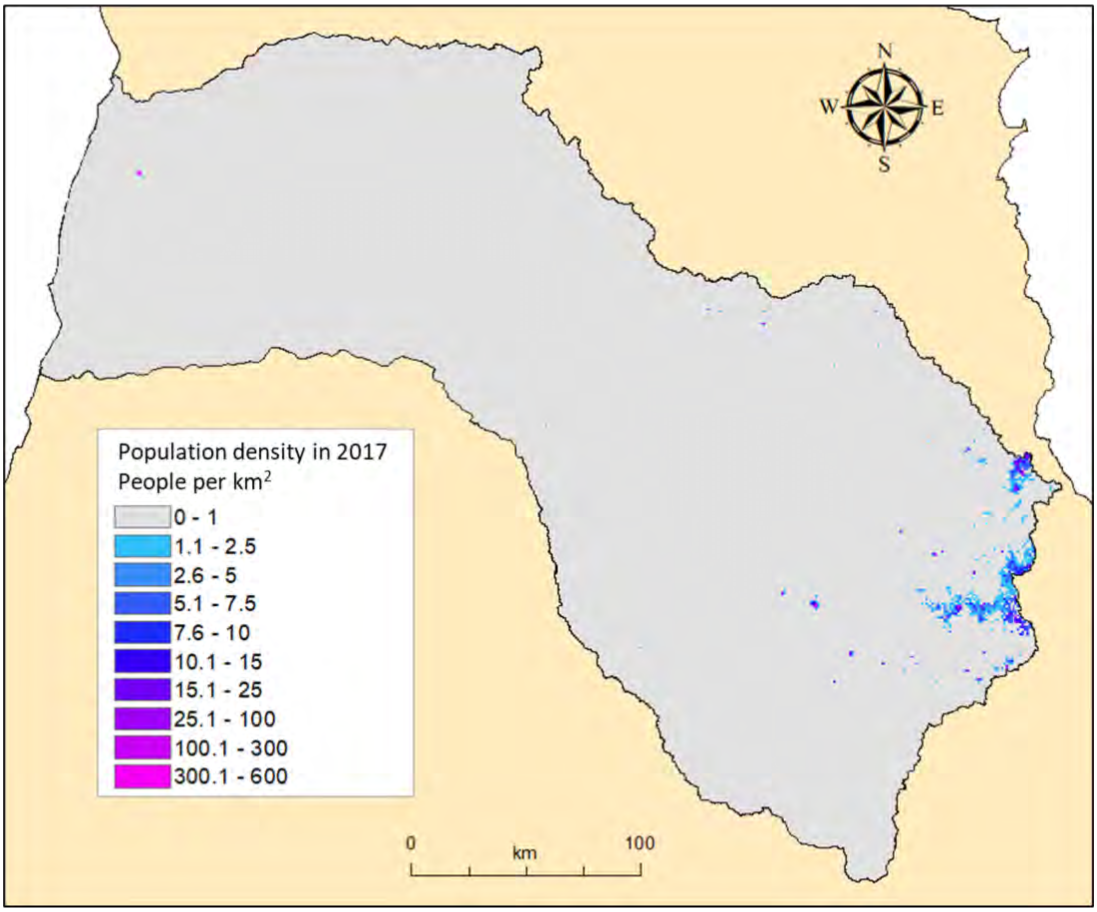
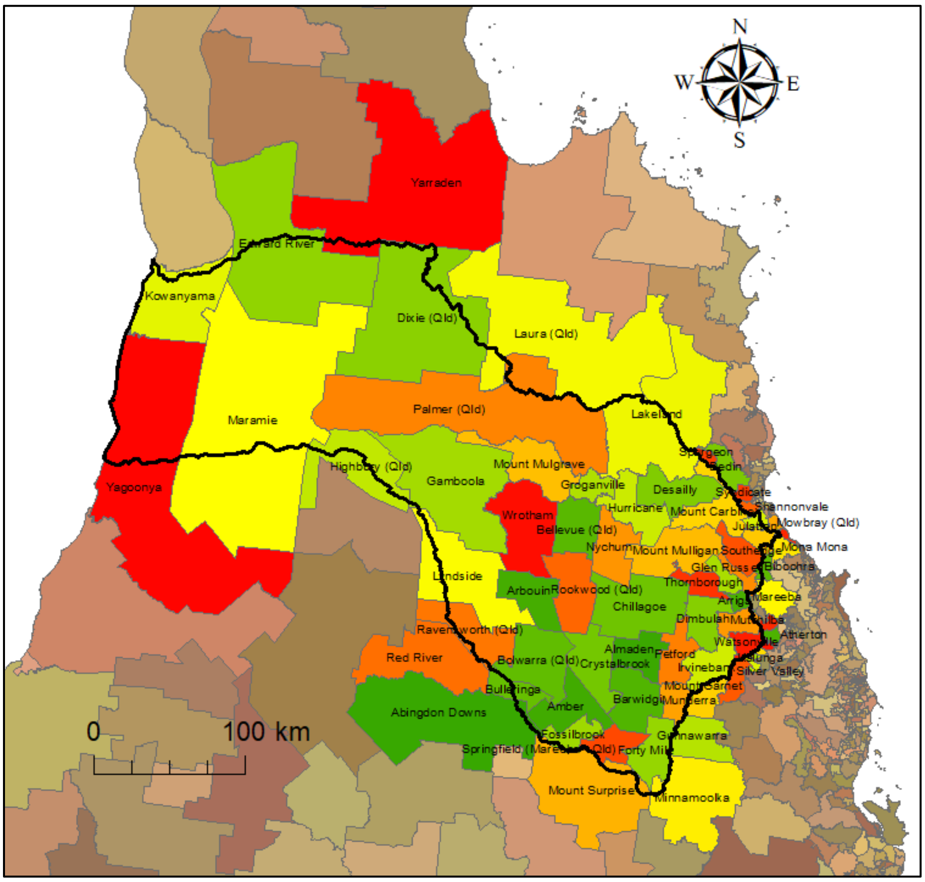


Figure 11. Population density map for the Mitchell catchment in 2017, expressed in number of people per km^2. Data source: Australian Bureau of Statistics, 2017.

(a)



(b)

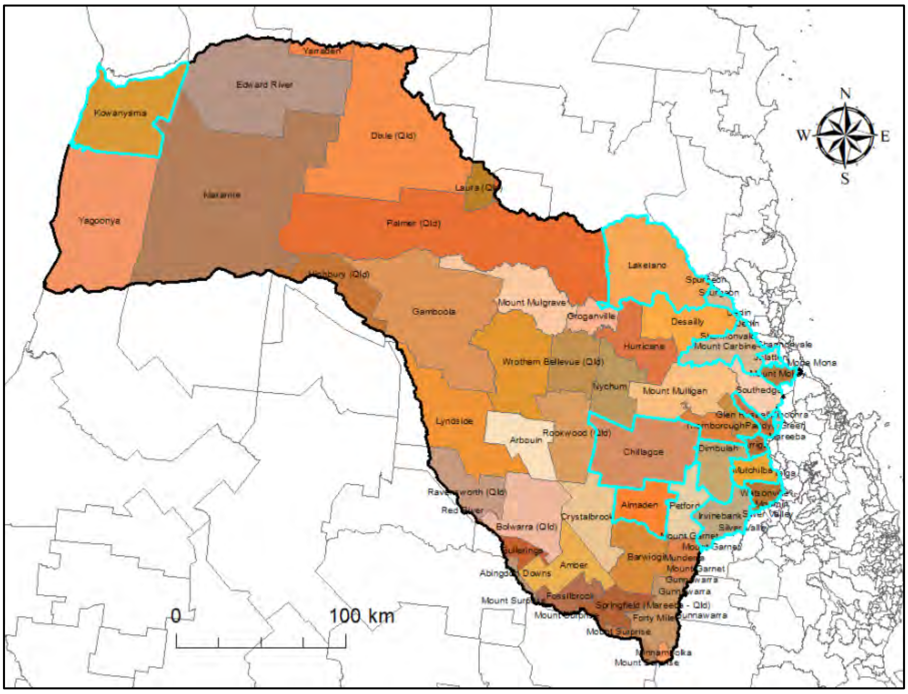


Figure 12. (a) The mosaic of state suburbs within the Mitchell catchment as determined by the Australian Bureau of Statistics (Australian Bureau of Statistics, 2016). State suburbs that are wholly within or span the boundary of the Mitchell catchment are shown in bright colours. (b) State suburbs outlined in blue in combination contain almost the entire population of the Mitchell catchment.

The demographic profile of five largest SSCs by population size with all or part of their area in the Mitchell catchment is shown in Table 1, based on ABS ‘quickstats’ data from the 2016 census (Australian Bureau of Statistics, 2017). Table 1 also shows Socio-Economic Indexes for Areas (SEIFA) data for 2016 published by the ABS (Australian Bureau of Statistics, 2008, 2018b). SEIFA data report the following measures: (i) Index of Relative Socio-economic Disadvantage (IRSD), (ii) Index of Relative Socio-economic Advantage and Disadvantage (IRSAD), (iii) Index of Economic Resources (IER), and (iv) Index of Education and Occupation (IEO). SEIFA indexes indicate that the five largest SSCs by population in the Mitchell are relatively disadvantaged compared to the rest of Queensland, as four of these five SSCs fall within the bottom 40% of SSCs across the state on all the SEIFA measures.

As described by the ABS (Australian Bureau of Statistics, 2008), the IRSD index includes 17 different measures of relative disadvantage – thus a high SEIFA-IRSD score (or decile) indicates a ‘relative lack of disadvantage’ whereas a low SEIFA-IRSD score (or decile) indicates ‘relative greater disadvantage’. IRSAD index extends the IRSD index to also include measures of relative advantage (totalling 21 measures of advantage and disadvantage), with a low IRSAD score (or decile) now indicating ‘relative greater disadvantage and lack of advantage’ and a high IRSAD score (or decile) indicating ‘relative lack of disadvantage and greater disadvantage’. The IER index is constructed from 15 variables relating to household economic resources (e.g., income, expenditures, home ownership, unemployment, ownership of an unincorporated enterprise) within an SSC. A low SEIFA-IER score (or decile) indicates a ‘lack of access to economic resources’, and vice versa. Finally, the SEIFA-IEO index captures nine measures of education and occupation-related skills at both ends of the spectrum. A low SEIFA-IEO score (or decile) indicates ‘relatively lower education and occupation status’ of individuals resident in an SSC, and vice versa.

As summarised in Table 1, of the five largest SSCs by population size with at least part of their area in the Mitchell catchment, Kowanyama is the most relatively disadvantaged followed by Mareeba, with those SSCs falling within the lowest 10% and 20% of Queensland’s SSCs for all four SEIFA measures, respectively.

Table 1. Key demographic indicators for five largest state suburbs (SSC) by population size with all or part of their area in the Mitchell catchment, based on ABS Census 2016.

Indicator	Unit	Mareeba	Julatten	Dimbulah	Arriga	Kowanyama	Queensland
Total population	number	11,079	1,091	1,050	1,079	944	4,703,193
Aboriginal and/or Torres Strait Islander population, as % of total	%	12.27	5.59	7.90	56.72	90.68	3.97
Male population, as % of total	%	49.47	52.52	52.00	92.22	47.78	49.37
Population density	people/km^2	22.96	7.05	1.40	6.90	0.37	2.72
Median age	years	41	50	48	33	29	37
Median weekly gross household income	$	1,041	1,034	921	1,303	944	1,402
Average people per household	number	2.5	2.4	2.4	2.7	3.4	2.6
Level of highest educational attainment – Bachelor Degree level and above	number	839	94	67	9	26	693,412
Level of highest educational attainment – Year 12	number	1,228	114	128	31	76	625,959
Level of highest educational attainment – Year 10	number	1,449	131	147	29	185	488,554
SEIFA: Index of Relative Socio-economic Disadvantage[1]	-	919 (2)	959 (4)	927 (2)	973 (4)	580 (1)	983
SEIFA: Index of Relative Socio-economic Advantage and Disadvantage[1]	-	907 (2)	936 (3)	924 (3)	967 (5)	676 (1)	971
SEIFA: Index of Economic Resources[1]	-	942 (2)	995 (4)	956 (2)	979 (3)	536 (1)	1009
SEIFA: Index of Education and Occupation[1]	-	899 (2)	936 (4)	940 (4)	956 (5)	755 (1)	964

Data sourced from the ABS 2016 census (Australian Bureau of Statistics, 2017) via 'quickstats', date accessed 13 Sept 2021.

[1] Socio-Economic Indexes for Areas (SEIFA) scores for 2016 report SSC-specific scores and their corresponding decile within Queensland (in brackets) relative to the Queensland mean (in the right-most column). Lower SEIFA scores (smaller deciles) indicate greater disadvantage. Nationally, SEIFA score is standardised against a mean of 1000 (i.e., national mean) with a standard deviation of 100 (Australian Bureau of Statistics, 2008, 2018b). Data source: ABS 2016 census (Australian Bureau of Statistics, 2017) via 'quickstats', date accessed 13 Sept 2021.

1.9 Project objectives

The main objectives of NESP Northern Australia Environmental Resources Hub Project 4.6 are to:

- Develop a pilot set of SEEA EA compliant accounts for ecosystem assets in and ecosystem service flows from the Mitchell catchment. The set of accounts should comprise an ecosystem asset extent account, an ecosystem asset condition account (both with ecosystem assets grouped by ecosystem type), and supply and use tables for ecosystem service flows in biophysical and monetary terms.
- Quantify the supply and use of important ecosystem services from key ecosystem assets (grouped by ecosystem type) in biophysical terms.
- Estimate the supply and use of important ecosystem services from key ecosystem assets (grouped by ecosystem type) in monetary terms; monetary valuations to be produced using SEEA EA-compliant methods for estimating the exchange value, or exchange-equivalent value of ecosystem services flows.
- Communicate research findings to diverse stakeholders in the Mitchell catchment, state and federal government, and the academic community.

In addition, Project 4.6 will conduct research on the following topics with the aim of assisting on-going development of the SEEA EA framework and its implementation in Australia and internationally:

- Investigate whether SEEA EA-compliant condition indicators can be configured appropriately to report on the condition of interlinked ecosystem assets (e.g., rivers, floodplains and wetlands) in an environment that experiences considerable seasonal and inter-annual variability in rainfall and river flows
- Investigate whether mechanisms can be developed to produce meaningful SEEA EA-compliant valuations of cultural ecosystem services.

2. Ecosystem extent

2.1 Ecosystem accounting model

Ecosystem accounting involves compilation and reporting of data on ecosystems and ecosystem services in a standardised format, in accordance with the guidelines provided in the SEEA EA framework (United Nations et al. 2021). To maintain consistency in ecosystem account developments and reporting, this project follows the general model of 'Ecosystem Extent → Ecosystem Condition → Ecosystem Services → Benefits' (see Figure 1) outlined in the National Strategy and Action Plan for Environmental Economic Accounting (Section 1.1) as the core ecosystem accounting model for this report. Similar core model for ecosystem accounting has also been described in detail in Eigenraam and Obst (2018), and is also applied by IDEEA Group (2020) and Eigenraam et al. (2016) in their development of ocean accounts for Geographe Bay and marine and coastal ecosystem accounts for Port Phillip Bay, respectively.

The core ecosystem accounting model 'Ecosystem Extent → Ecosystem Condition → Ecosystem Services → Benefits' conceptualises that the type, extent and condition of ecosystem assets affect the flow of ecosystem goods and services from those assets. Figure 13 depicts the core ecosystem accounting model for this project showing the process involved in producing the set of inter-related ecosystem accounts and the types of data each account contains. This core model (Figure 13) links the extent and condition of each ecosystem asset to the quantity of ecosystem services supplied to society from that ecosystem asset, collates ecosystem assets by ecosystem type and then reports the corresponding contributions to benefits provided. The account tables are underpinned by individual ecosystem assets, grouped into ecosystem types, and each ecosystem asset is spatially located via a geographic information system (GIS). Thus, ecosystem extent, ecosystem condition and the supply of ecosystem services could all be represented in map format as well as in accounting tables. The accompanying Ecosystem Accounts for the Mitchell Catchment report presents results as accounting tables and as GIS maps – as appropriate for the focus of each particular presentation.

Following the scheme of Figure 13, the *ecosystem extent account* is the first of the series of accounts to be constructed and forms the basis for subsequent development of the *ecosystem condition account*, *ecosystem service supply and use accounts* and *ecosystem service monetary supply and use accounts*. In Project 4.6, we follow the core model of Figure 13 to describe the methodology which underpins development of SEEA ecosystem accounts.

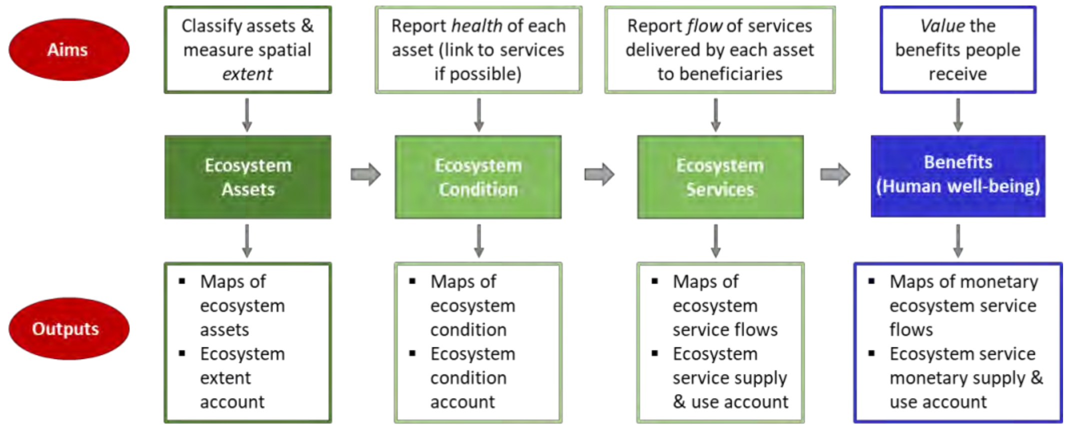


Figure 13. Core model of ecosystem accounting following the environmental-economic accounting approach. Adapted from Commonwealth of Australia (2018, p.2)

2.2 Ecosystem assets

Three types of spatial accounting units are outlined in the SEEA EA Final Draft (United Nations, 2021) as cited by Farrell et al. (2018). The first spatial unit is the overall ecosystem accounting area (EAA), which can be delineated by, for example, administrative or river basin boundaries. The EAA is the accounting area of interest for the account compiler; for Project 4.6, this is the Mitchell catchment. The second spatial unit refers to mutually exclusive areas of ecosystem types (ETs) that are contained within the EAA boundary. An ecosystem type is defined as an ecosystem that 'reflects a distinct set of abiotic and biotic components and their interactions' (SEEA EA 2021, p.44). Ecosystem types are determined using the SEEA ecosystem type reference classification (Keith et al. (2020), cited in SEEA EA, 2021; Annex 3.2 p.67-69) which is based on the global ecosystem typological framework of the International Union for Conservation of Nature Global Ecosystem Typology (IUCN GET). As described in Keith et al. (2020), the IUCN GET follows a hierarchical classification system in which at the top level (Level 1), the global biosphere is divided into five *realms* (terrestrial, subterranean, freshwater (including saline water bodies on land), marine and atmosphere), followed by Level 2 (*biomes*) and then Level 3 (ecosystem functional groups (EFGs)). Level 3 EFGs are nested within Level 2 biomes, and Level 2 biomes are nested within Level 1 realms, as shown in Figure 14.

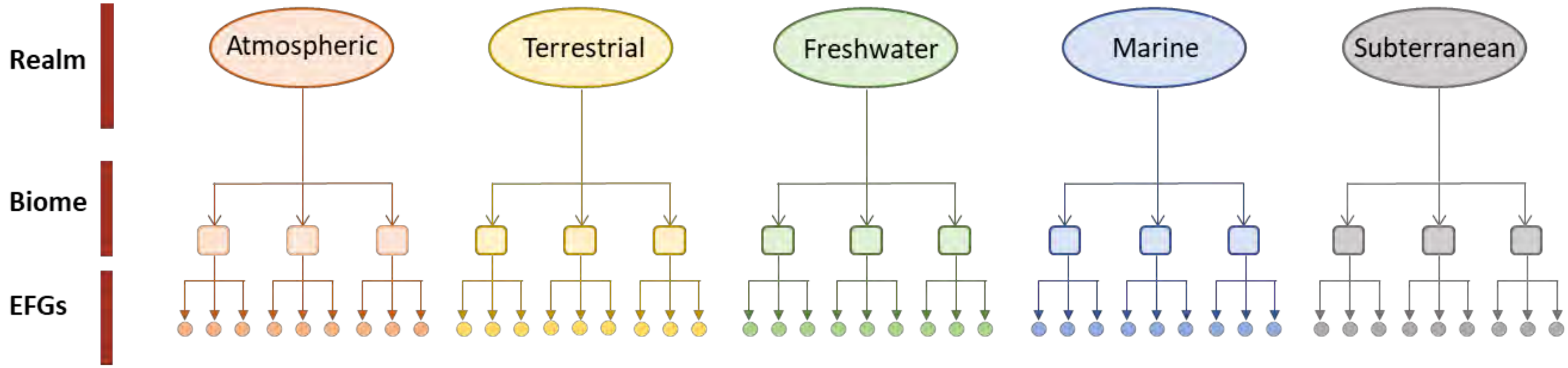


Figure 14. Hierarchical classification system of the International Union for Conservation of Nature Global Ecosystem Typology (IUCN GET). Adapted from Keith et al. (2020). For a complete list of ecosystem functional groups and their respective biomes, please refer to the SEEA EA Final Draft (United Nations Statistics Division (2021) Annex 3.2: IUCN Global Ecosystem Typology, p67–69).

The third spatial unit, which is also referred to as the *primary spatial unit*, is called an *ecosystem asset*. Ecosystem assets (EAs) are defined by SEEA EA as 'contiguous spaces of a specific ecosystem type characterised by a distinct set of biotic and abiotic components and their interactions' (United Nations Statistics Division, 2021; p.43). This means that multiple ecosystem assets can belong to the same *ecosystem type* classification i.e., the same EFG. For example, separate areas of saltmarsh should be regarded as separate *ecosystem assets* within the same *ecosystem type* (saltmarsh). Figure 15 shows ecosystem assets and ecosystem types within an ecosystem accounting area as described in SEEA EA. As shown in Figure 15, the ecosystem accounting area in this example consists of six ecosystem assets categorised into four ecosystem types (forest, urban area, cropland and lake).

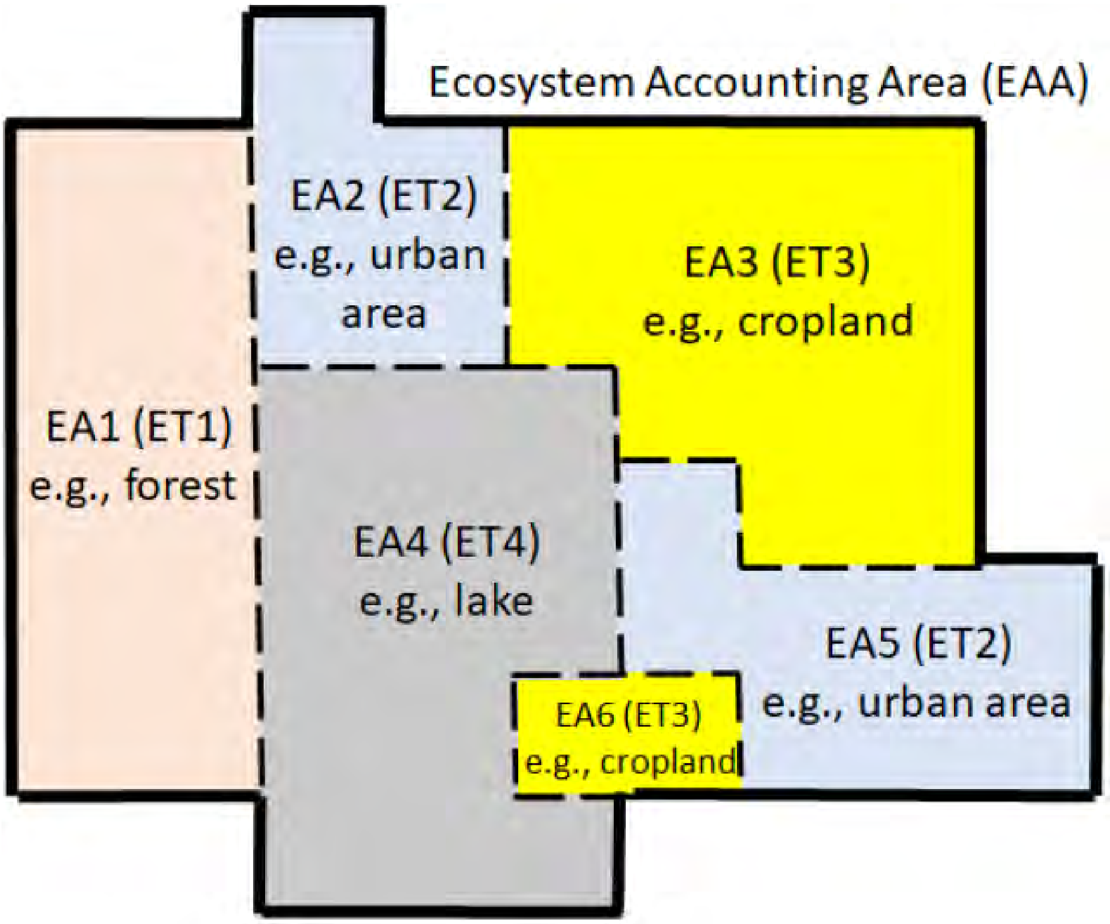


Figure 15. Ecosystem assets (EAs) and ecosystem types (ETs – synonymous with IUCN GET's ecosystem functional groups) within an ecosystem accounting area as described in SEEA EA Final Draft. EAs represent individual, contiguous ecosystems. Source: United Nations Statistics Division (2021, p.48).

Ecosystem types for the Mitchell catchment EAA are determined by cross-walking between the Broad Vegetation Groups of Queensland (Neldner et al. 2019) and IUCN GETs, in consultation with experts at the Queensland Herbarium (see Data Inventory for further details). The spatial layer for the Broad Vegetation Groups of Queensland (Version 4 2019[6], based on Regional Ecosystem (RE) mapping Version 12) was used as the underlying ecosystem asset spatial layer for the Mitchell catchment. For the Mitchell catchment EAA, ecosystem types include for example EFGs of coastal shrublands and grasslands; tropical-subtropical dry forests and thickets; pyric tussock savanna; and seasonal floodplain marshes.

The cross-walking exercise for the Mitchell catchment revealed that all but three Queensland broad vegetation groups (BVGs) can be matched to EFGs from IUCN GETs. For the three BVGs, estuary, non-remnant[7] and water[8], that do not have the corresponding EFGs, the following datasets are used to further describe their features, characteristics or land uses (see the Data Inventory for further details):

- Non-remnant: QLUMP datasets, available for the years 1999 and 2015 (see Data Inventory for further details);
- Waterbodies
    - Digital Earth Australia Waterbodies (Krause, Newey, Alger, & Lymburner, 2021) dataset. Data are continuously updated and only the most up-to-date dataset is readily available for download at the time of access (data downloaded on 16 March 2021)
    - Persistent dry-season waterholes from the Landsat archive for the Northern Australia Water Resource Assessment (NAWRA) (Ticehurst, 2018). Data are continuously updated and only the most up-to-date dataset is readily available for download at the time of access (data downloaded on 18 May 2021)
    - Water Observation from Space (WOfS) (Geoscience Australia, 2015). Data are continuously updated and only the most up-to-date dataset is readily available for download at the time of access (data downloaded on 3 March 2021)
- Estuarine and freshwater watercourse areas: Queensland Watercourse Areas (State of Queensland (Department of Nautral Resources and Mines), 2021) dataset. Data are continuously updated and only the most up-to-date dataset is readily available for download at the time of access (data downloaded on 16 March 2021); and
- Rivers: Queensland Watercourse Lines (State of Queensland (Department of Natural Resources and Mines), 2021) dataset. Data are continuously updated and only the most up-to-date dataset is readily available for download at the time of access (data downloaded on 4th March 2021).

Table 2 shows an indicative layout for an ecosystem extent account table. Table 3 shows an indicative layout for a supplementary extent account for water bodies. Table 4 shows an indicative layout for a supplementary extent account for rivers where rivers are described by their linear features.

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[6] Version 5 Broad Vegetation Groups mapping is now available, however it was released after the spatial framework for Project 4.6 had already been established (May 2021).
[7] see Appendix E: Remnant and non-remnant vegetation as defined by the Vegetation Management Act (1999).
[8] The BVG class *water* is the category used in the spatial dataset of Queensland BVGs to capture any land area that has been mapped as water and is neither remnant, non-remnant nor estuary.

Table 2. SEEA EA indicative layout of an ecosystem extent account (i.e., shell ecosystem extent account) showing indicative structures of ecosystem types that are present in the Mitchell catchment. The unit of area is hectares. EFG refers to ecosystem functional group (synonymous here with ecosystem type). The symbol ### indicates values in hectares. Opening and closing extents refer to the total area of ecosystem assets, grouped by ecosystem type, at the start and end of an accounting period, respectively.

Realm	**Terrestrial**					**Freshwater–terrestrial**		**Marine–freshwater–terrestrial**		**Broad Vegetation Groups of Queensland**		
Biome	T1 Tropical-subtropical forests			T3 Shrublands & shrubby woodlands	…	TF1 Palustrine wetlands		MFT1 Brackish tidal				
EFG	T1.1 Tropical-subtropical lowland rainforests	T1.2 Tropical-subtropical dry forests and thickets	T1.3 Tropical-subtropical montane forests	T3.1 Seasonally dry tropical shrublands	…	TF1.2 Subtropical-temperate forested wetlands	TF1.4 Seasonal floodplain marshes	MFT1.2 Intertidal forests & shrublands	MFT1.3 Coastal saltmarshes & reedbeds	Estuary	Water	Non-remnant
Opening extent	###	###	###	###	…	###	###	###	###	###	###	###
Additions to extent												
Managed expansion	###	###	###	###	…	###	###	###	###	###	###	###
Unmanaged expansion	###	###	###	###	…	###	###	###	###	###	###	###
Reductions in extent												
Managed reductions	###	###	###	###	…	###	###	###	###	###	###	###
Unmanaged reductions	###	###	###	###	…	###	###	###	###	###	###	###
Net change in extent	###	###	###	###	…	###	###	###	###	###	###	###
Closing extent	###	###	###	###	…	###	###	###	###	###	###	###

Table 3. SEEA EA indicative layout of a supplementary (shell) extent account for waterbodies, dry-season wetlands and water observations from space by ecosystem types (i.e., EFGs), presented in terms of area (hectares) and count for the most recent year (2020 for the Mitchell ecosystem accounts).

Realm	**Terrestrial**					**Freshwater–terrestrial**		**Marine–freshwater–terrestrial**		**Broad Vegetation Groups of Queensland**		
Biome	T1 Tropical-subtropical forests			T3 Shrublands & shrubby woodlands	…	TF1 Palustrine wetlands		MFT1 Brackish tidal				
EFG	T1.1 Tropical-subtropical lowland rainforests	T1.2 Tropical-subtropical dry forests and thickets	T1.3 Tropical-subtropical montane forests	T3.1 Seasonally dry tropical shrublands	…	TF1.2 Subtropical-temperate forested wetlands	TF1.4 Seasonal floodplain marshes	MFT1.2 Intertidal forests & shrublands	MFT1.3 Coastal saltmarshes & reedbeds	Estuary	Water	Non-remnant
Waterbodies												
Extent (ha)	###	###	###	###	…	###	###	###	###	###	###	###
Count (no.)	###	###	###	###	…	###	###	###	###	###	###	###
Dry-season wetlands												
Extent (ha)	###	###	###	###	…	###	###	###	###	###	###	###
Count (no.)	###	###	###	###	…	###	###	###	###	###	###	###
Water from space												
Extent (ha)	###	###	###	###	…	###	###	###	###	###	###	###
Count (no.)	###	###	###	###	…	###	###	###	###	###	###	###

Table 4. SEEA EA indicative layout of a supplementary (shell) extent account for rivers by ecosystem types. Rivers are described by the area covered by water (in km^2) and by their linear features, shown as length in kilometres for the most recent year (2020 for the Mitchell ecosystem accounts).

Realm	**Terrestrial**					**Freshwater–terrestrial**		**Marine–freshwater–terrestrial**		**Broad Vegetation Groups of Queensland**		
Biome	T1 Tropical-subtropical forests			T3 Shrublands & shrubby woodlands	…	TF1 Palustrine wetlands		MFT1 Brackish tidal				
EFG	T1.1 Tropical-subtropical lowland rainforests	T1.2 Tropical-subtropical dry forests and thickets	T1.3 Tropical-subtropical montane forests	T3.1 Seasonally dry tropical shrublands	…	TF1.2 Subtropical-temperate forested wetlands	TF1.4 Seasonal floodplain marshes	MFT1.2 Intertidal forests & shrublands	MFT1.3 Coastal saltmarshes & reedbeds	Estuary	Water	Non-remnant
Estuarine: major/minor perennial												
Watercourse area (km^2)	###	###	###	###	…	###	###	###	###	###	###	###
Watercourse line (km)	###	###	###	###	…	###	###	###	###	###	###	###
Estuarine: major or minor non-perennial												
Watercourse area (km^2)	###	###	###	###	…	###	###	###	###	###	###	###
Watercourse line (km)	###	###	###	###	…	###	###	###	###	###	###	###
Freshwater: major/minor perennial												
Watercourse area (km^2)	###	###	###	###	…	###	###	###	###	###	###	###
Watercourse line (km)	###	###	###	###	…	###	###	###	###	###	###	###
Freshwater: major/minor non-perennial												
Watercourse area (km^2)	###	###	###	###	…	###	###	###	###	###	###	###
Watercourse line (km)	###	###	###	###	…	###	###	###	###	###	###	###

3. Ecosystem condition

The ecological health of ecosystem assets in the accounting area, grouped by ecosystem types, is reported in the *ecosystem condition* account. When accounting for ecosystem condition it is important to assess any human-induced deterioration in condition leading to decline in the biophysical service flows from that asset separately from natural variability in condition (Obst & Eigenraam, 2017). SEEA EA regards human-induced deterioration in condition as 'degradation', whereas variation in condition due to non-human-induced environmental variation is considered 'natural variability', i.e., not 'degradation' (L Hein et al. 2016). Measuring ecosystem asset condition at the beginning and end of an accounting period will identify any changes in condition occurring during that period.

The ecosystem condition account is an important component in the SEEA EA framework. As the aim is to periodically report asset condition consistently using a fixed-format ecosystem condition account, any changes in condition identified from this account can prompt further investigation of the cause of the change (H. Keith, Vardon, Stein, & Lindenmayer, 2019).

3.1 Ecosystem condition variables

In ecosystem accounting, the quality of an ecosystem asset is assessed 'in terms of its abiotic and biotic characteristics' (United Nations Statistics Division, 2021; p.81). Ecosystem condition characteristics are organised in accordance with the SEEA ecosystem condition typology (Czúcz et al. 2021 Table 1, p.5; United Nations Statistics Division, 2021 Table 5.1, p.86), a hierarchical structure encompassing three groups of characteristics (abiotic, biotic, and landscape and seascape) at the higher level and six classes of characteristics at the next lower level (abiotic physical state; abiotic chemical state; biotic compositional state; biotic structural state; biotic functional state; and landscape and seascape) as shown in Figure 16.

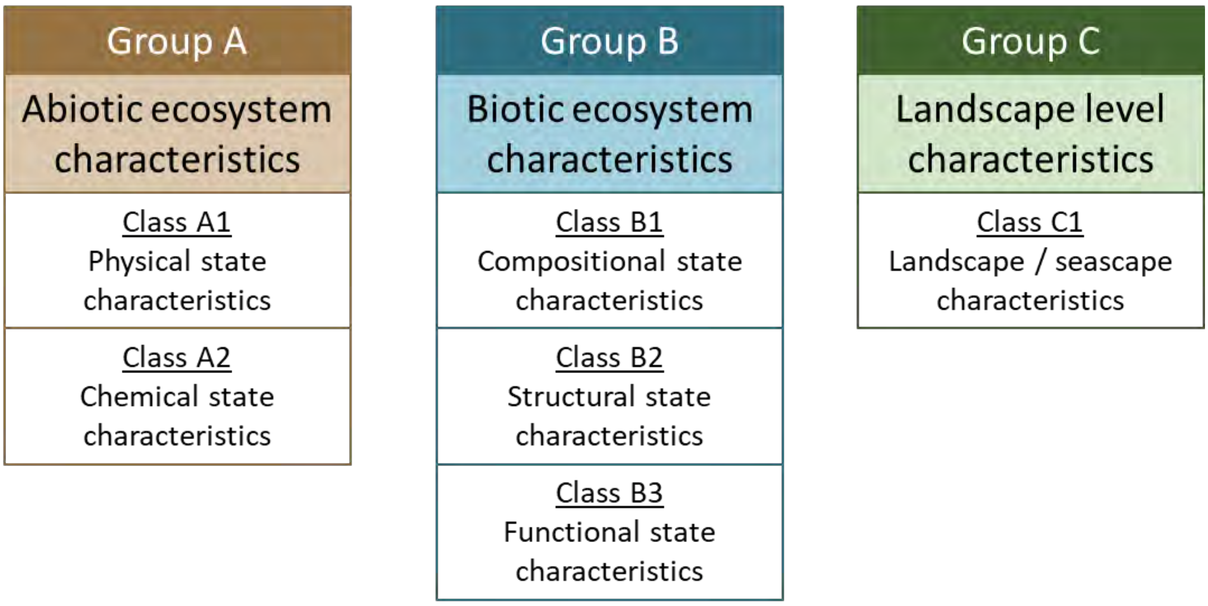

Figure 16. The SEEA EA Ecosystem Condition Typology. Source: Czúcz et al. (2021) Table 1, p.5; United Nations Statistics Division (2021) Table 5.1, p.86.

Quantitative values or metrics that are used to describe these characteristics are referred to as *variables*, *indicators* and *indices;* each term comes with specific definitions (Czúcz et al. 2021). Any quantitative value or metric describing the state of individual characteristics of an ecosystem asset is called an *ecosystem condition variable* (United Nations Statistics Division, 2021; p.90). Ecosystem condition variables with a 'strong direct normative interpretation (i.e., distinguishing 'good' from 'bad') for policy decisions' (Czúcz et al. 2021; p.2) are referred to as *ecosystem condition indicators*. Values attached to ecosystem condition indicators are <u>rescaled</u> versions of ecosystem condition variables, typically to a common dimensionless scale ranging from 0 or 0% as the bottom value to 1 or 100% as the top value (United Nations Statistics Division, 2021; p.91). Finally, an *ecosystem condition index* is derived from aggregation of ecosystem condition indicators. This aggregation is typically undertaken to provide a single summary number per ecosystem type. The progression from *variables* to *indicators* and then to *indices* involves a three-stage process as described in H. Keith et al. (2020, p.15–17), reproduced here as Figure 17.

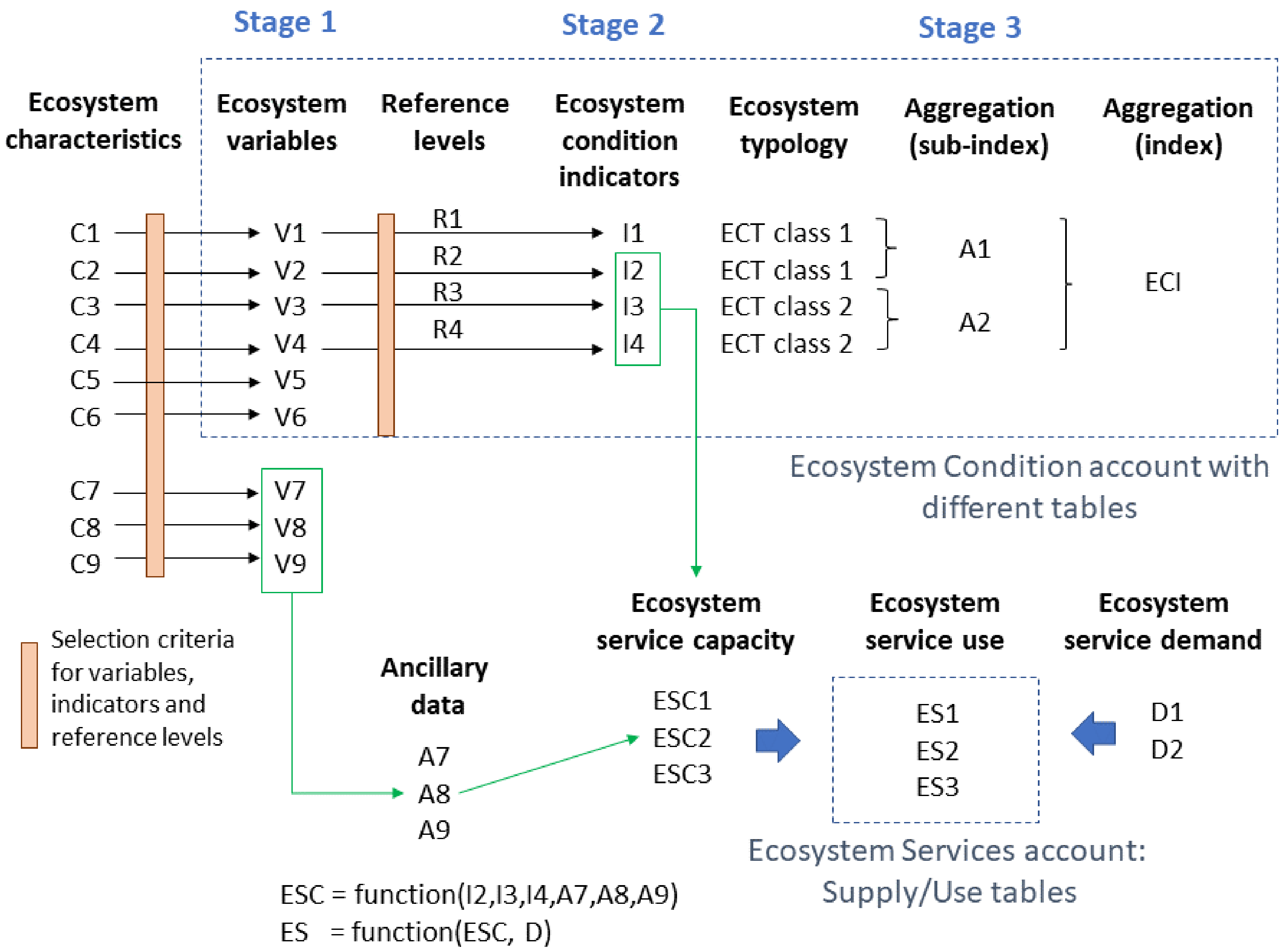

Figure 17. A framework proposed by H. Keith et al. (2020, p.15–17) for deriving an ecosystem condition index for reporting the health of the ecosystem, and for selecting variables, indicators and ancilliary data to inform the capacity of an ecosystem asset to supply particular ecosystem services

In Project 4.6, publicly and currently available data and information (including research findings) that describe the abiotic and biotic state and landscape characteristics of ecosystem assets in the Mitchell River catchment were compiled (Figure 18). This compilation of condition variables was informed by:

- guidelines and examples provided in the SEEA EA (United Nations Statistics Division, 2021; Table 5.1 on p.86 and Table 5.6 on p102–103)
- a recent review of existing ecosystem condition indicators used to assess ecosystem condition in case study locations from around the world (Maes et al. 2020).

The temporal resolution of the compiled data, however, varies quite significantly and data are relatively sparse (Table 5). Relevant data and information from Figure 18 appropriate for the relevant ecosystem types are selected for inclusion in the ecosystem condition variable account for the Mitchell catchment, using examples of ecosystem condition variables for the different ecosystem types provided in SEEA EA documentation as a guide (United Nations Statistics Division, 2021; Table 5.6 on p102–103).

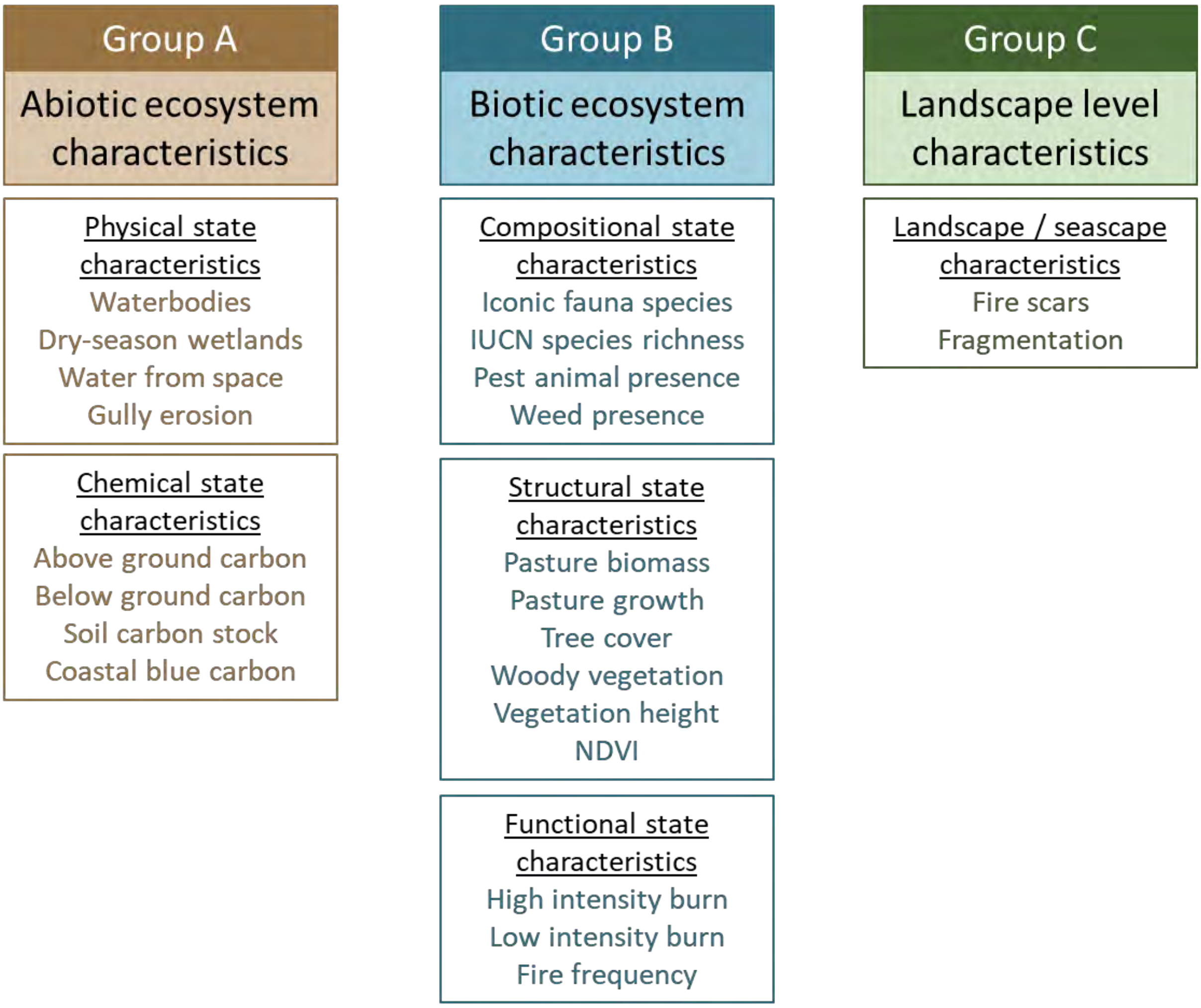

Figure 18. List of information and data identified for the Mitchell catchment that describe abiotic, biotic and landscape/seascape characteristics of ecosystem assets, grouped by ecosystem types, organised according to SEEA EA Ecosystem Condition Typology (Figure 16).Note that for some ecosystem types only a subset of these data are appropriate for inclusion in ecosystem condition variable accounts.

Table 5. Temporal resolution of information and data collected to describe abiotic, biotic and landscape/seascape characteristics of terrestrial ecosystem types. ✓ indicates that data for the year are available and × indicates data for the year are not readily and/or freely available. 'Most recent year' means that the data have been continuously updated and only the most up-to-date dataset is readily available for download at the time of access, which is taken to be the year 2020. Please refer to Data Inventory for the full documentation of each data source.

Variable	Unit	Temporal resolution	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	…	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Abiotic: physical state characteristics																																			
Waterbodies	ha & no.	Most recent year[i]	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	✓
Dry-season wetlands	ha & no.	Most recent year[j]	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	✓
Water from space	ha & no.	Most recent year[k]	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	✓
Watercourse areas	km^2	Most recent year[l]	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	✓
Watercourse lines	km	Most recent year[m]	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	✓
Gully erosion[a]	m/yr, m^3/yr	Between 2000–2004	×	×	×	×	×	×	×	×	×	×	×	×	×	×	one value					×	×	×	×	×	×	×	×	×	×	×	×	×	×
Abiotic: chemical state characteristics																																			
Above ground carbon[b]	Mg/ha/yr	Mean 1993–2012	×	×	×	×	×	×	×	one mean value for these years																		×	×	×	×	×	×	×	×
Above ground carbon[c]	Mg/ha	2010	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	✓	×	×	×	×	×	×	×	×	×	×
Below ground carbon[c]	Mg/ha	2010	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	✓	×	×	×	×	×	×	×	×	×	×
Soil carbon[d]	Mg/ha	2010	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	✓	×	×	×	×	×	×	×	×	×	×
Coastal blue carbon	g/yr & g	2019	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	✓	×
Biotic: compositional state characteristics																																			
Iconic fauna species[e]	presence	Vary by species	2008;1970–1989;1970–2018;1967–1997;1946; 1996–2012;1964-2015;2015–2021;1966–2014;1994–2018;1911–1991;1993–2019																																
Iconic species habitat	ha	2012	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	✓	×	×	×	×	×	×	×	×
IUCN species richness	species no.	Most recent year[n]	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	✓
Pest animals[f]	presence	Present day		Number of pest animal species presence compiled from multiple one-off surveys & datasets																															
Weeds[f]	presence	Present day		Number of weed species presence compiled from multiple one-off surveys & datasets																															

Table 5 (continued).

Variable	Unit	Temporal resolution	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	…	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Biotic: structural state characteristics																																			
Pasture biomass	kgDM/ha	Annual, 1955–present	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Tree cover	mean %	Some years, annual	×	×	✓	✓	×	✓	✓	×	✓	✓	×	×	✓	×	✓	×	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	×	×
Woody vegetation	3 classes, ha	some years, annual	×	×	✓	✓	×	✓	✓	×	×	✓	×	×	✓	×	✓	✓	×	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	×
Vegetation height	metres	One-off for 2009	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	✓	×	×	×	×	×	×	×	×	×	×	×
Biotic: functional state characteristics																																			
High intensity burn	ha	Annual, 2003–2010	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	✓	✓	✓	✓	✓	✓	×	×	×	×	×	×	×	×	×	×
Low intensity burn	ha	Annual, 2003–2010	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	✓	✓	✓	✓	✓	✓	×	×	×	×	×	×	×	×	×	×
Fire frequency[f]	no.	Between 2000–2019	×	×	×	×	×	×	×	×	×	×	×	×	×	×	one frequency value for these years																		×
Pasture growth	kgDM/ha/yr	Annual, 1955–present	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
NDVI[g]	index	Annual, 1992–present	×	×	×	×	×	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Landscape level characteristics																																			
Fire scars (area burned)[h]	ha	2000 –2019	×	×	×	×	×	×	×	×	×	×	×	×	×	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	×
Fragmentation[f]	ha	one-off	Pre- and post-clearing mean patch size in hectare estimated using FRAGSTATS																																

[a] Estimates of soil erosion (i.e., median volume (m^3) and annual gully erosion (m^3/ha/year)) were based on data collected between 2000 and 2004 as detailed in Brooks et al. (2008) (see Data Inventory).

[b] This dataset on above ground carbon biomass was available as a single average value over a 20-year period (1993–2012) obtained from Liu et al. (2015).

[c] Above ground and below ground carbon biomass came from the same source (see Spawn et al. (2020).

[d] Soil carbon was obtained from the baseline mapping of Australian soil organic carbon stocks by CSIRO in 2010 (see Viscarra Rossel et al. (2014).

[e] Based on sightings of iconic fauna species by individuals as recorded in Atlas of Living Australia (ala.org.au). This variable, however, is not included in the ecosystem condition variable account (Chapter 3) because it cannot be regarded as a measure of density of the relevant species, although it may provide some indication of species distribution. A lack of sightings of a species does not indicate the species is absent. Even if it were, the reasons for absence might not be related directly to the condition of the assets of the relevant ecosystem type that provides its habitats (e.g., hunting pressure from humans or predators). In this regard the remaining area of suitable habitat for the iconic fauna species within an ecosystem type is regarded as a more meaningful metric for assessing ecosystem condition. Iconic fauna species refer to animal species listed as *critically endangered* or *endangered* in Queensland's Nature Conservation (Animals) Regulations 2020.

[f] Please refer to Chapter 5 'Pressures on ecosystem condition' for information on the methods for deriving (i) presence of invasive species (pest animals and weeds), (ii) the three classes of fire frequency metric, and (iii) the fire fragmentation metric. These three metrics are used to inform ecosystem condition as well as environmental pressures.

[g] The data source for the normalised difference vegetation index (NDVI) is described in the Data Inventory. This variable is not included in the ecosystem condition variable account (Chapter 3) because it had already been used as one an input variable in the construction of some of the condition metrics that are listed in this table (e.g., pasture biomass as estimated by AussieGRASS (Stone, Day, Carter, Bruget, & Panjkov, 2010) and also as one of the input variables for Ground Cover Disturbance Index (a metric for environmental pressures, see Section 5.3). Furthermore, the relationship between NDVI (a measure of 'greenness') and ecosystem condition may be positive or negative. For example, NDVI would likely provide a higher reading where blooms of blue-green algae are present in lakes, waterways and coastal waters. A simple measure of 'greenness' gives little information about the biophysical properties of the plant material displaying that greenness. Field observations are necessary to turn NDVI, which is a ratio of near-infrared radiation and visible radiation, into meaningful metrics concerning plant matter.

[h] Temporal coverage extends to the year 2020, however, coverage for the year 2020 may be incomplete.

[i] Data downloaded on 16 March 2021.

[j] Data downloaded on 18 May 2021.

[k] Data downloaded on 3 March 2021.

[l] Data downloaded on 16 March 2021

[m] Data downloaded on 4 March 2021.

[n] Data downloaded on 29 Jan 2021

Of the variables listed in Figure 18 and Table 5, presence of iconic fauna species and normalised difference vegetation index (NDVI) are not included in the Ecosystem Condition Variable Account for the Mitchell catchment for the following reasons:

Iconic faunal species presence

Data on iconic faunal species presence were compiled from reported sightings of individuals as recorded in Atlas of Living Australia (ala.org.au). This variable is not included in the ecosystem condition variable account (Chapter 3) because reported sightings of iconic species cannot be regarded as a measure of density for the relevant species, although they provide some indication of species distribution (assuming the species were identified correctly). A lack of sightings of a species does not indicate the species is absent. Even if it were, the reasons for absence might not be related directly to the condition of ecosystem assets with the ecosystem types that provide its habitat (e.g., absence could arise due to hunting pressure from humans or predators). In this regard the remaining area of suitable habitat for the species (i.e., the variable 'iconic fauna species habitat' in Table 5) within an ecosystem type is regarded as a more meaningful metric for assessing ecosystem condition, hence, this variable is retained and is reported in the ecosystem condition variable account. Iconic fauna species refer to animal species listed as *critically endangered* or *endangered* in Queensland's Nature Conservation (Animals) Regulations 2020[9].

Normalised difference vegetation index (NDVI)

The data source for the normalised difference vegetation index (NDVI) is described in the Data Inventory. This variable is not included in the ecosystem condition variable account (Chapter 3) because it has already been used as one of the input variables in some of the other condition metrics that are listed in Table 5 (e.g., pasture biomass as estimated by AussieGRASS (Stone et al. 2010) and also as one of the input variables for the Ground Cover Disturbance Index (a metric of environmental pressures, see Section 5.3). Furthermore, the relationship between NDVI (a measure of 'greenness') and ecosystem condition may be positive or negative. For example, NDVI would likely provide a higher reading where blooms of blue-green algae are present in lakes, waterways and coastal waters. A simple measure of 'greenness' gives little information about the biophysical properties of the plant material displaying that greenness. Field observations are necessary to turn NDVI, which is a ratio of near-infrared radiation and visible radiation, into meaningful metrics concerning plant matter.

Table 6 shows an indicative layout for one of many possible ways of presenting ecosystem condition variable account tables. A separate data inventory detailing sources of datasets for all condition variables was also developed as a technical support document accompanying this report. Details on data sources on weeds and pests are provided separately in the next section.

[9] Queensland's Nature Conservation (Animals) Regulations 2020 are available at legislation.qld.gov.au/view/html/inforce/current/sl-2020-0136, date accessed 4 October 2020.

Table 6. Indicative layout of an ecosystem condition variable account adapted from SEEA EA (United Nations Statistics Division, 2021; p.91) and Warnell et al. 2020 for selected years.

SEEA EA Ecosystem Condition Typology Class	Variables		Ecosystem Type 1 (e.g., T1 Tropical-subtropical forests)		Ecosystem Type 2 (e.g., TF1 Palustrine wetlands)	
	Variable name	Unit	Year	Year	Year	Year
Abiotic Physical state	Variable 1	ha				
	Variable 2	no.				
	Variable 3	km				
Abiotic Chemical state	Variable 4	Mg/ha				
	Variable 5	Mg/ha				
	Variable 6	tonnes/ha				
Biotic Compositional state	Variable 7	No.				
	Variable 8	ha				
Biotic Structural state	Variable 9	kg/ha				
	Variable 10	kg/ha/year				
	Variable 11	%				
Biotic Functional state	Variable 12	ha				
	Variable 13	ha				
Landscape characteristics	Variable 14	ha				
	Variable 15	ha				

3.2 Datasets on invasive species

In Australia, datasets on invasive species are compiled by regional governments, non-governmental organisations and private stakeholders. Spatially specific data on invasive species are typically recorded based on on-ground observations under specific monitoring program(s) that are in-place in that locality. On-ground observations of the presence of invasive species tend to be one-off events because repeated monitoring of the same site over discrete time periods is cost-prohibitive and would require additional funding arrangements. Hence, data from repeated observations of invasive species on the same land area are currently not available. Consequently, only spatially specific data on species presence, rather than species density, have been collected by these organisations.

In this study, we utilise four regional invasive species datasets that are available through the Queensland Government's spatial database (Qspatial), which is updated every 4–10 years, as candidate condition variable(s) for inclusion in the SEEA EA condition account for the Mitchell River catchment. The four datasets (see the Project 4.6 Data Inventory for further details) are:

- Pest Central (weed and pest animal)
- Annual Pest Distribution Surveys
- WildNet and Atlas of Living Australia
- Combination of datasets.

Data on invasive species present within the Mitchell River ecosystem accounting area require further GIS processing to ensure compatibility with the format required by SEEA EA. GIS processing was completed through a two-stage process, as follows.

Stage 1

The first stage involved identification of priority invasive species, as a subset of all species, that are present within the Mitchell River catchment. Priority invasive species were identified through a structured review of local, regional, state and national invasive species management frameworks. These frameworks provide a list of predominant invasive species that were identified as priorities for management via a prioritisation framework. The choice of invasive species for inclusion in management frameworks is based on the following factors:

- the species' current extent within the jurisdictional area concerned
- the species' ability to establish across all terrestrial landscapes (with a risk that they would then impact the ecological condition of different ecosystem types)
- the species' inclusion in established legislated responsibilities for government, non-governmental organisations and private actors to monitor their presence across spatial and temporal scales
- the species' ability to impact a region's triple bottom line (i.e., environmental, social and economic values)
- the availability of control methods for effective management of the species.

Stage 2

The second stage involved systematic searches of invasive species databases to identify and extract datasets pertaining to priority invasive species only. Priority invasive species datasets were then converted to a spatial format consistent with the SEEA EA framework. All data from the four data sources (Pest Central, Annual Pest Distribution Surveys, WildNet, Atlas of Living Australia, and other sources (see Project 4.6 Data Inventory for further details) were converted to **18.5 km × 18.5 km grid format** following the Annual Pest Distribution Survey framework. This was completed by

- converting all datasets with polygon and line data to point format using the centroids function on QGIS
- transposition of all point data to the Annual Pest Distribution Survey grid system, with grid squares tagged only if a priority weed or pest animal was present (i.e., Not present = 0, Present = 1).

The grid data file was then overlaid onto the Mitchell River catchment's ecosystem assets, which identified all ecosystem assets in which priority invasive species had been reported to be present within an 18.5 km × 18.5 km grid.

Due to the coarseness of the grid format used, and the consequent mapping of invasive species in assets of ecosystem types in which they would not normally be found, invasive species were removed from ecosystem assets for which the ecological characteristics of the underlying ecosystem type would limit their presence (e.g., aquatic weeds were not deemd to be present within assets of terrestrial ecosystem types when assets of those ecosystem types occurred within an 18.5 km × 18.5 km grid square in which the weed's presence had been reported). The criteria used for the removal of invasive species from ecosystem types were:

- aquatic invasive species were removed from terrestrial ecosystem assets
- terrestrial invasive species were removed from aquatic ecosystem assets.

Results from Stage 1 and Stage 2 were combined to identify which local, state and national management frameworks would be applicable for managing priority species in their relevant jurisdictions. Results from GIS processing in Stage 2 reported the estimated presence of priority weed and pest animal species in all ecosystem types within the Mitchell River catchment.

3.3 Progression from Stage 1 to Stage 2 in ecosystem condition account development

Moving from Stage 1 (Variables) to Stage 2 (Indicators) in ecosystem condition account development (see Figure 17) requires additional information on the reference level and additional knowledge about the normative interpretation of the values of the variables. In order to determine a reference level for an indicator or a reference condition, SEEA EA suggests referring to the most un-disturbed/pristine state and measuring the change that has occurred from that position (United Nations Statistics Division, 2021; Section 5.3.3). The use of individual reference levels for each indicator is helpful for obtaining a robust representation of overall ecosystem condition. However, it is also suggested that an aggregation of these individual reference levels should be compiled to produce an overall ecosystem reference condition to increase the usefulness and relevance of a subsequently condition Index (Stage 3 in Figure 17) to policy makers. Most of the condition variables summarised in Table 5 and Figure 18 lack not only information on reference levels, but also readily accessible knowledge about normative interpretation of the quantitative values in their respective units. This lack of readily accessible information prevented further development of those variables into indicators. For these reasons, whilst a Stage 1 Ecosystem Variable Condition Account was produced for the Mitchell catchment, a Stage 2 Ecosystem Condition Indicator Account was not produced in this Project.

Whilst a methodological framework for compiling the ecosystem condition accounts (Figure 17) has been clearly set out, H. Keith et al. (2020) emphasise that the intended objective of ecosystem condition accounts may differ across case studies and therefore the development of suitable indicators and measures of condition should be sufficiently flexible to reflect this (H. Keith et al. 2019). The different objectives for which ecosystem accounts could be compiled can be broadly categorised using a two-dimensional framework; one dimension spanning a spectrum from intrinsic to instrumental values, and the other from anthropogenic to eco-centric worldviews (Heather Keith et al. 2020). This categorisation can help identify the key outcomes required by the end users and thus inform development of an ecosystem condition account that is appropriate for their purposes (Heather Keith et al. 2020). Nonetheless, most ecosystem condition accounts will generally be driven by a similar underlying ecological understanding of appropriate measures of ecosystem condition and, ultimately, also by the available data (Heather Keith et al. 2020).

Measuring ecosystem condition requires a reliable, robust and fairly comprehensive set of indicators, however, selection and development of such indicators can be challenging because of complex ecosystem dynamics that often reflect several intertwined ecological processes (Duku, Rathjens, Zwart, & Hein, 2015; Van Oudenhoven, Petz, Alkemade, Hein, & De Groot, 2012). A wide variety of indicators could be used to assess condition; however, complications arise because potential indicators are often likely to be heavily correlated and context specific (Holub, Tappeiner, & Tappeiner, 1999).

4. Supplementary information and ancillary data

In addition to the condition variables listed in Table 5, additional information and findings from other studies focusing on particular ecosystem types were also compiled in this study to supplement the available condition variables, as follows:

- Aquatic Conservation Assessment (ACA) values
- protected areas
- annual rainfall.

4.1 Aquatic Conservation Assessment values

Aquatic Conservation Assessment (ACA) values (Updated Version 1.1 published 30 August 2020) were developed by the Queensland Department of Science and Environment (Wetland*Info*: wetlandinfo.des.qld.gov.au/wetlands/assessment/assessment-methods/aca) for assessing the conservation values of wetlands within Queensland (Department of Environment and Science, 2018; Department of Environment and Science Queensland, 2019). ACAs were developed using the Aquatic Biodiversity Assessment and Mapping Methodology (AquaBAMM) (Clayton, Fielder, Howell, & Hill, 2006). As of May 2019, ACAs have been completed for all freshwater riverine and non-riverine (i.e.,palustrine and lacustrine) wetlands in Queensland, and for intertidal and subtidal habitats that are within Central Queensland state water (Department of Environment and Science Queensland, 2019, 2020). AquaBAMM is a comprehensive method that uses available criteria, indicators and measures drawn from the national and international literature in combination with expert opinion to produce Aquatic Scores (ASs) per polygons (sub-sections of river segments, non-riverine palustrine wetlands, and non-riverine lacustrine wetlands) and polylines (river segments) within Queensland. As described by the Queensland Department of Environment and Science (2020), results from AquaBAMM ACAs can be used to:

- prioritise on-ground investments in the protection and rehabilitation of aquatic ecosystems
- assist planning processes involving water resources at local and regional scale
- contribute to impact assessment associated with large-scale development
- identify aquatic assets
- inform prioritisation processes that incorporate social and economic dimensions

Aquatic scores for watercourse areas and watercourse lines within the Mitchell's ecosystem types are reported in the Supplementary Information section of the Mitchell's Ecosystem Accounts.

4.2 Protected areas in Queensland

Ancillary information on the extent and types of protected areas in Queensland, published by Queensland Government's Department of Environment and Science (State of Queensland (Department of Environment and Science), 2021), have also been compiled as Supplementary Information in the Ecosystem Accounts for the Mitchell catchment. Protected areas, based on data collected from 2003 to 2021, refer to areas classified as National Park, National Park – Cape York Aboriginal Land, State Forest, Forest Reserve, Resources

Reserve, Nature Refuge, Important Bird Area and Essential Habitat managed by Queensland Parks and Wildlife Services under the following Acts:

- Nature Conservation Act 1992
- Forestry Act 1959 .

Protected areas in Queensland are reported as extent (in ha) and category per ecosystem type in the Mitchell catchment.

4.3 Ancillary data on rainfall

Ancillary data on annual rainfall for the Mitchell catchment were obtained from the Bureau of Meteorology for the period between 1880 and 2020. Each year of rainfall data were converted into a raster with a 0.05 degree grid (approximately 5 km by 5 km) following the methodology outlined in Jeffrey et al. (2001). In total, 140 rasters for the years 1880 to 2020 were merged to produce a mean value per grid cell which were them mapped and tabulated by ecosystem types across the Mitchell catchment. Annual rainfalls are reported in the Ecosystem Accounts for the Mitchell catchment in the form of maps and tables as Supplementary Information alongside the Ecosystem Condition Variable Account.

5. Pressures on ecosystem condition

To support reporting of information on ecosystem condition, data and information on a range of pressures that could affect ecosystem condition were also compiled to provide an alternative or indirect assessment of ecosystem condition (European Commission, 2016; p.28) in the Mitchell River catchment. Data on environmental pressures are often used as surrogates for ecosystem condition in situations where limited data are available on the state of ecosystem condition (United Nations Statistics Division, 2021, p.104). Whilst there is likely to be a time lag between the onset of a pressure and associated impacts on ecosystem condition (European Commission, 2016; p.28), measuring and reporting environmental pressures is still likely to be useful for informing policy direction and the potential need for investments in environmental management. In Queensland, data on a selected number of ecosystem pressures such as invasive species presence and fires have typically been collected by relevant local and state authorities to inform on-ground land management. These data can be utilised to supplement the ecosystem condition variable account.

In Project 4.6, data and information on the following environmental pressures were collected to produce an *Ecosystem Asset Pressure Account*:

- fire frequency
- fragmentation
- ground cover disturbance
- land clearing
- pest animal and weed presence
- river disturbance.

5.1 Fire pressure

Fire is integral to the shaping of Australia's landscapes, influencing the composition of flora and fauna contained within them. Post-European settlement, however, fire use in Australia has become a significant pressure on Australia's ecosystems as the burning regimes that have emerged are no longer being considered natural.

To assess fire as a pressure in the Mitchell River catchment, this study utilised the 'Fire regime – Queensland series' available via the Queensland Government's Qspatial website (Queensland Herbarium, 2021b) to determine whether current fire regimes, specifically burn frequencies, were within recommended guidelines for each regional ecosystem (RE) present in ecosystem types in the Mitchell River catchment. Developed from the Queensland Government's 'Fire management guidelines' (Queensland Herbarium, 2021b), the fire regime spatial layer collates and visualises recommended burn patterns for Queensland REs and is 'based on quantitative and qualitative information from published literature and expert observation and opinion' (Queensland Government, 2021). Suggested burning regimes are developed purely from an ecological perspective (i.e., for the maintenance and enhancement of biodiversity), and do not consider burning regimes to protect infrastructure and human life (Queensland Government, 2021).

Current fire frequencies for assets of the different ecosystem types in the Mitchell River catchment were obtained using the following three-step procedure:

1. Fire frequency data from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) 250 m satellite imagery between 2000 and 2019 were downloaded from the TERN portal (tern.org.au)
2. From this 20-year dataset, the number of times an individual pixel was burnt (i.e., fire burn frequency) was recorded. The number of burns per pixel ranged from zero burns over 20 years to a maximum of 20 burns over 20 years. Pixel data are then converted into a GIS raster.
3. The GIS raster was overlayed over the Mitchell River catchment's ecosystem types (See Appendix D for further detail on the ecosystem types, including the crosswalk between IUCN GETs EFGs and the Queensland BVGs).

The GIS raster containing the *current fire frequency* for ecosystem assets in the Mitchell catchment (i.e., current fire frequency) is then compared against the *recommended fire frequency* based on Queensland Government's fire management guidelines (Queensland Herbarium, 2021b), from which three fire pressure variables are produced for each polygon (i.e., ecosystem asset):

- the percentage area of that asset for which *current fire burn frequency* falls is within the *recommended fire burn frequency*
- the percentage area of that asset for which *current fire burn frequency* is below the *recommended fire burn frequency*
- the percentage area of that asset for which *current fire burn frequency* is above the *recommended fire burn frequency.*

These three variables that report on fire burn frequency relative to ecosystem guidelines can be regarded as fire pressure metrics for each ecosystem asset within ecosystem types in the Mitchell catchment. Each ecosystem asset has different sets of fire pressure metrics reflecting spatially explicit patterns of fire pressure on asset condition across the landscape.

Following SEEA EA guidelines (United Nations Statistics Division, 2021; paragraph 5.54, p.90), fire pressure metrics per ecosystem type are calculated as the area-weighted arithmetic mean of fire pressure metrics for ecosystem assets within that ecosystem type within the Mitchell River catchment. This process is repeated for each of the three metrics (burnt too frequently, burnt within guidelines, not burnt frequently enough) to produce an area- weighted average for each fire pressure metric per ecosystem type (Table 7).

In a further step, a single fire pressure indicator score is produced from the separate fire pressure metrics for each ecosystem type. The fire pressure indicator is derived as a scaled representation of 'the percentage area of the ecosystem type for which current fire burn frequency falls within the recommended fire burn frequency guidelines'. The rescaling uses the following formula (United Nations Statistics Division, 2021; p.92):

$$I = \frac{V - V_{Low}}{V_{High} - V_{Low}}$$

where I is the indicator score, V is the value of the fire pressure metric, V_{High} is the 'high condition' score (i.e., lowest fire pressure metric) and V_{Low} is the 'low condition' score (i.e., highest fire pressure metric). In this instance, V_{High} corresponds to the entire area of the ecosystem type being burned within the recommended fire frequency guidelines (i.e., 100% of the observed area) and V_{Low} corresponds to none of the ecosystem type being burned within the recommended fire frequency guidelines (i.e., 0% of the observed area). The resulting indicator score, I, is thus sits on a dimensionless scale ranging between 0 (bottom value i.e., poor condition due to high pressure) and 100 (top value i.e., excellent condition due to absence of pressure).

A limitation in the available fire regime spatial layer on Qspatial is that its mapping is based on RE Version 6, whereas the ecosystem types for the Mitchell River catchment were developed by cross-walking the IUCN GETs EFGs with RE – Version 12 (i.e., RE mapping Version 12 is the basis for Version 4.0 Remnant 2017 Broad Vegetation Groups of Queensland). This discrepancy has resulted in a number of Version 6 REs no longer being represented in Version 12 REs. In these instances, REs from the fire regime spatial layer were removed from the assessment and are therefore not included in the *Ecosystem Asset Pressure Account* for the Mitchell catchment. As a consequence, the fire regime pressure assessment provides (slightly) less than full coverage of the ecosystem types area (see Table 7).

Table 7. Indicative layout for reporting fire pressure metrics and a fire pressure indicator. The indicator reports a fire pressure score ranging between 0 (bottom value, i.e., poor condition due to high pressure) and 100 (top value i.e., excellent condition due to absence of pressure).

Fire pressure indicator	Unit	Ecosystem Type 1	Ecosystem Type 2	Ecosystem Type 3
Current fire burn frequency falls within the *recommended fire frequency range*	%	Value between [0,100]	Value between [0,100]	Value between [0,100]
Current fire burn frequency falls below the *recommended fire frequency range*	%	Value between [0,100]	Value between [0,100]	Value between [0,100]
Current fire burn frequency is above the *recommended fire burn frequency range*	%	Value between [0,100]	Value between [0,100]	Value between [0,100]
Fire pressure indicator	**-**	**Value between [0,100]**	**Value between [0,100]**	**Value between [0,100]**
Percentage of land area covered by fire pressure indicator	%	≤ 100%	≤ 100%	≤ 100%

5.2 Fragmentation

Land clearing and conversion of native ecosystems to other uses is the leading cause of habitat fragmentation worldwide and an uneven distribution of fragmentation patterns is observed across the world's biomes (Haddad et al. 2022; Jacobson, Riggio, M. Tait, & E. M. Baillie, 2019). Fragmentation is recognised as a key determinant of ecosystem degradation (i.e., human-induced deterioration in condition) (Bryan-Brown et al. 2020), resulting in loss of biodiversity (Haddad et al. 2022) and impairing the capacity of ecosystems to supply ecosystem services (Bryan-Brown et al. 2020; Dobson et al. 2006). Fragmentation refers to subdivision of habitats and native spaces into smaller disjoint patches (Haddad et al. 2022; Jacobson et al. 2019) leading to an altered spatial arrangement or configuration of ecosystem assets across the landscape (Herse, With, & Boyle, 2018).

Fragmentation can be regarded both as a condition variable (see Figure 18) and as an environmental pressure. Pressures associated with expansion of agricultural land (de Oliveira, de Carvalho Júnior, Gomes, Guimarães, & McManus, 2017), installation of infrastructure for natural resource extraction (Langlois, Drohan, & Brittingham, 2017; Racicot et al. 2014), transport networks (Donaldson & Bennett, 2004), recreational trails (Ballantyne, Gudes, & Pickering, 2014)) and human settlements (Yang, Yang, Luo, & Huang, 2019)) are just some of the commonly studied drivers of fragmentation in remnant ecosystems. Following Bryan-Brown et al. (Bryan-Brown et al. 2020), the FRAGSTATS (Version 4) tool (K. McGarigal, Cushman, & Ene, 2012) is used in this study to quantify fragmentation in ecosystem types in the Mitchell catchment. FRAGSTATS produces a range of metrics to describe different aspects of fragmentation, for illustrative purposes for the Mitchell catchment (where there is generally very little fragmentation), the mean patch size metric from FRAGSTATS for pre- and post-clearing is reported in as a condition variable in the Ecosystem Condition Variable Account for the Mitchell.

A pressure indicator value for fragmentation is derived by expressing the post-clearing mean patch size as a percentage of pre-clearing mean patch size for each ecosystem type, resulting in indicators values of between 0 (bottom value, poor condition) and 100 (top value, excellent condition). In this treatment, the mean patch size from the pre-clearing period was taken to be the desired state of environmental condition, thus the reference level corresponds to an indicator score of 100.

5.3 Ground cover disturbance

QLUMP data indicates that the major land use in the Mitchell catchment is open range cattle grazing on native vegetation on unimproved land (Petheram et al. 2018b, p.107; Stokes et al. 2017). Globally, loss of biodiversity and ecosystem services as a result of land degradation has been estimated to cost more than 10 per cent of annual global gross product, with land degradation primarily driven by unsustainable management of cropland and grazing lands (IPBES, 2018). Reductions in woody vegetation cover and ground cover have been associated with land degradation resulting in soil erosion and biodiversity loss (see Waters et al. (2019) for a more extensive discussion on this topic). In the context of land management in the Mitchell, it is likely that cattle grazing pressure and trampling will be a primary driver of ground cover disturbance through the mechanisms described by Waters et al. (2019).Thus, we consider ground cover disturbance as a proxy for grazing pressure in rangeland ecosystem types in the Mitchell.

Ground cover is defined as 'non-woody vegetation (forbs, grasses and herbs), litter, cryptogamic crusts and rock in contact with the soil surface' (Tindall et al. 2012, p.1 citing Muir et al. 2011). Three quarters of the land area in Queensland has woody foliage cover of less than 20%, and ground cover is one of the indictors used by regional natural resource management groups and catchment management groups to inform land management efforts in these areas (Scarth et al. 2006). The Biodiversity Assessment Team within the Queensland Government's Department of Environment and Science developed a Ground Cover Disturbance Index (GCDI) to 'assess aspects of rangeland biodiversity condition' (State of Queensland (Department of Environment and Science), n.d.). For each of Queensland's REs, GDCI combines mean ground cover (1988 – 2009) with ground cover trend over the same period to produce a Ground Cover Disturbance score. This score is then assessed against the RE's natural level of ground cover to produce GCDI. The GCDI assigns attribute values ranging from 1 to 16 to each RE, following the matrix shown in Figure 19. GCDI can only be calculated for areas with less than 20% foliage projective cover (where satellites can see the ground cover through the trees) and for remnant areas within the BVGs (see Appendix E for definitions of remnant and non-remnant vegetation in the Vegetation Management Act 1999). Water and 'low change' (e.g., bare rock) areas, supplied with the GDCI dataset, are also excluded (see Data Inventory). Table 8 provides an indicative layout for reporting GCDI as a proxy for grazing pressure.

1988 – 2009 Ground Cover mean

1988 – 2009 Ground Cover trend

Disturbance Level	High Ground Cover	Above Mean Ground Cover	Below Mean Ground Cover	Low Ground Cover
Increasing trend	1 - Very Low (Benchmark)	5 - Low	9 - Medium	13 - High
Slight increase in trend	2 - Very Low (Benchmark)	6 - Low	10 - Medium	14 - High
Slight decrease in trend	3 - Low	7 - Medium	11 - High	15 – Very High
Decreasing trend	4 - Low	8 – Medium	12 - High	16 – Very High

Figure 19. Ground Cover Disturbance Index: matrix of attribute values. Reproduced from State of Queensland 2020 Metadata for Queensland Ground Cover Disturbance Index – Version 2.0 (State of Queensland (Department of Environment and Science), n.d.).

Table 8. Indicative layout for reporting GCDI as a proxy for grazing pressure. Indicator values are a combination of mean ground cover (1988 – 2009) with ground cover trend over the same period to produce a Ground Cover Disturbance score ranging from 1 (Very low ground cover disturbance and increasing ground cover trend) to 16 (Very high ground cover disturbance and decreasing ground cover trend). Percentages reported for each ecosystem type represent the percentage of the ecosystem type area assigned to each GCDI attribute score. GDCI values are only reported for ecosystem types that have grazing as the predominant land use as mapped under QLUMP. Benchmark attribute values are 1 (Very low ground cover disturbance and increasing ground cover trend) and 2 (Very low ground cover disturbance and slightly increasing ground cover trend).

GCDI attribute description	GCDI attribute value	Ecosystem Type 1	Ecosystem Type 2	Ecosystem Type 3
High ground cover & increasing trend	1	%	%	%
High ground cover & slightly increasing trend	2	%	%	%
High ground cover & slightly decreasing trend	3	%	%	%
High ground cover & decreasing trend	4	%	%	%
Above mean ground cover & increasing trend	5	%	%	%
Above mean ground cover & slightly increasing trend	6	%	%	%
Above mean ground cover & slightly decreasing trend	7	%	%	%
Above mean ground cover & decreasing trend	8	%	%	%
Below mean ground cover & increasing trend	9	%	%	%
Below mean ground cover & slightly increasing trend	10	%	%	%
Below mean ground cover & slightly decreasing trend	11	%	%	%
Below mean ground cover & decreasing trend	12	%	%	%
Low ground cover & increasing trend	13	%	%	%
Low ground cover & slightly increasing trend	14	%	%	%
Low ground cover & slightly decreasing trend	15	%	%	%
Low ground cover & decreasing trend	16	%	%	%

5.4 Land clearing

The Statewide Landcover and Trees Study (SLATS) is a Queensland Government initiative to monitor vegetation extent (and therefore vegetation loss) attributable to human activities, via a combination of automated and manual mapping techniques, across the state (Queensland Government (Department of Science Information Technology and Innovation), 2017). The mapping of woody vegetation is based on Landsat satellite imagery and supported by other data sources (Queensland Department of Environment and Science, 2018). SLATS was established to support regulation and monitoring of native vegetation clearing under the Vegetation Management Act 1999 (VMA) (Queensland Government (Department of Science Information Technology and Innovation), 2017).

Mapped products from SLATS are used as input data for the following purposes (Queensland Government (Department of Science Information Technology and Innovation), 2017):

- updating regional ecosystem mapping
- assessing land management activities against vegetation management frameworks under the vegetation Management Act 1999
- informing vegetation management policies, land management policies, State of Environment reporting, Great Barrier Reef reporting, and biodiversity conservation and planning.

SLATS provides data on woody vegetation change between the first mapping period of 1988–1991 through to the most recent available mapping period at the time the Project 4.6 Ecosystem Accounts for the Mitchell were compiled (2017–2018). The following data from SLATS were used to inform levels of land clearing pressure for ecosystem types in the Mitchell River catchment:

- woody vegetation clearing data, measured as clearing rates in thousand hectares per year, for the clearing periods 1998–1991; 1991–1995; 1995–1997; 1997–1999; and then annually from 1999–2000 through to 2017–2018
- woody vegetation clearing by replacement land cover (pasture, crops, timber plantation, mining, infrastructure, settlement), measured in thousand hectares per year, for the clearing periods 1998–1991; 1991–1995; 1995–1997; 1997–1999; and then annually from 1999–2000 through to 2017–2018.

The dataset on woody vegetation clearing by replacement land cover includes additional information on ‘missed clearing in previous era’, ‘natural disaster damage’, ‘natural tree death’, ‘re-allocated class’ and ‘thinning’ in thousand hectares per year. Table 9 and Table 10 provide indicative layouts for reporting the rate of woody vegetation clearing, and the rate of woody vegetation clearing by replacement land cover, respectively, for selected years as a measure of the land clearing pressure exerted on ecosystem types in the Mitchell catchment.

Table 9. Indicative layout for reporting the rate of vegetation clearing (in thousands of hectares per year) by ecosystem types as a measure of land clearing pressure on ecosystem types in the Mitchell catchment.

Clearing period	Ecosystem Type 1	Ecosystem Type 2	Ecosystem Type 3	Ecosystem Type 4
1988–1991	###	###	###	###
1991–1995	###	###	###	###
1995–1997	###	###	###	###
1997–1999	###	###	###	###
1999–2000	###	###	###	###
2000–2001	###	###	###	###
…	…	…	…	…
2016–2017	###	###	###	###
2017–2018	###	###	###	###

Table 10. Indicative layout for reporting the rate of vegetation clearing (in thousands of hectares per year) by replacement cover for each relevant ecosystem type in the Mitchell catchment for selected years.

Replacement land cover	Ecosystem Type 1		Ecosystem Type 2		Non-remnant	Non-remnant
	2010–2011	2015–2016	2010–2011	2015–2016	2015–2016	2015–2016
Pasture	###	###	###	###	###	###
Crops	###	###	###	###	###	###
Timber plantation	###	###	###	###	###	###
Mining	###	###	###	###	###	###
Infrastructure	###	###	###	###	###	###
Settlement	###	###	###	###	###	###
Sub-total	####	####	####	####	####	####
Missed clearing in previous periods	###	###	###	###	###	###
Natural disaster damage	###	###	###	###	###	###
Natural tree death	###	###	###	###	###	###
Re-allocated class	###	###	###	###	###	###
Thinning	###	###	###	###	###	###
Total	####	####	####	####	####	####

5.5 Pest animal and weed presence

5.5.1 Invasive species: background and management

The introduction of weeds and pest animals (hereafter 'invasive species') to Australia has had a long, often intentional, history. It is estimated that approximately 2,700 weed species and over 80 pest animal species are now established on mainland Australia, contributing collectively towards $6 billion in damages to the Australian economy, as well as imposing additional costs on social, cultural and environmental assets (Friedel, 2020; Hart & Bomford, 2006; Invasive Species Council, n.d.).

Invasive species impacts can be represented by the 'invasion curve', which illustrates invasive species colonisation as a function of time against a range of variables, including invasive species abundance, management costs (time and financial), impacts on ecosystem service flows, etc. (Antunes & Schamp, 2017) (Figure 20). Generally, invasion follows a four-stage pathway (Victorian Government, 2010) comprising:

1. Prevention stage – where an invasive species is not present in the ecosystem and there are no impacts to ecosystem health from the invasive species. Management should focus on preventing the introduction of invasive species to the ecosystem.
2. Eradication stage – where small populations of invasive species become established in an ecosystem with evidence of no/limited impacts to ecosystem health from invasive species. Management should focus on removing all known invasive species populations from the ecosystem.
3. Containment stage – where invasive species populations rapidly expand in area and cause noticeable impacts to ecosystem health. Management should focus on containing the spread of invasive species populations both within the ecosystem and between neighbouring ecosystems within the landscape.
4. Asset based protection stage – where invasive species populations are widespread within the ecosystem and are causing significant impacts to ecosystem health. Management should focus on protecting assets within the ecosystem that contribute towards societal well-being.

The position of an invasive species on the invasion curve determines the most appropriate management response; with management being more cost-effective during the earlier stages of invasion (prevention and eradication) and becoming less cost-effective towards the latter stages of the invasion curve (containment and protection of assets).

Responsibility for the management of invasive species in Australia is shared between national, state, regional and local authorities. Within Queensland, the *Biosecurity Act 2014* (the Act) (State of Queensland, 2020) provides the regulatory framework for the management of invasive species through the imposition of a 'General Biosecurity Obligation'(GBO) on all individuals and landowners (Queensland Government (Department of Agriculture and Fisheries), 2021). Under the GBO, all individuals have responsibility for the management of invasive species, as well as other biosecurity matters[10], that are 'under

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[10] Other biosecurity matters are defined in Schedule 2 of the *Biosecurity Act 2014* and include Aquatic diseases, parasites and viruses; Restricted matter affecting animals; Noxious fish; and Restricted matter affecting plants. These biosecurity matters are outside the scope of this study.

their control; and that they know about, or should reasonably be expected to know about' (Queensland Government (Department of Agriculture and Fisheries), 2021[11]).

Under the Act, responsibility for invasive species management is determined by the type of biosecurity matter and the category that the species has been allocated to. Types of biosecurity matter are:

- Prohibited invasive matter – those invasive species that are not currently present in Queensland but, however, have the potential to significantly affect Queensland's triple bottom line (i.e., environmental, economic and social outcomes).
- Restricted invasive matter – those invasive species that are present within Queensland and are, or have the potential to, notably impact Queensland's triple bottom line (Table 11) (State of Queensland, 2020).

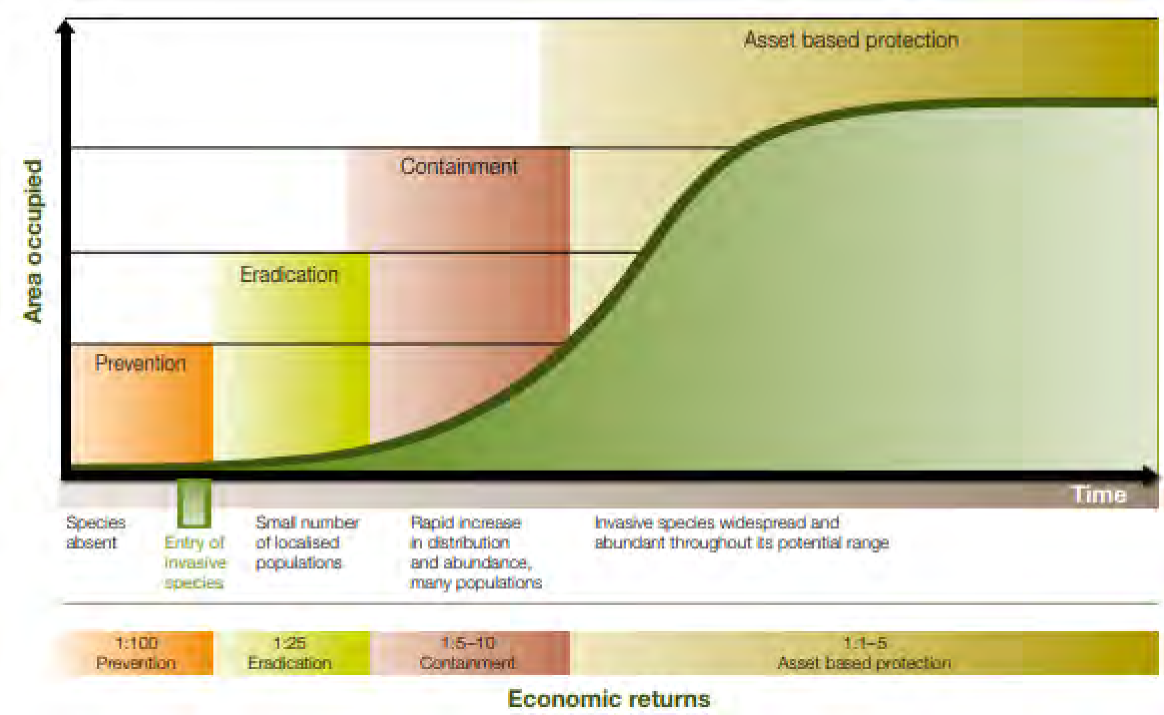

Figure 20. Generalised invasion curve, showing the four stages of invasive species invasion and economic returns in response to management through each stage. Source: Victorian Government (2010), Figure 2 on p.14.

[11] daf.qld.gov.au/business-priorities/biosecurity/policy-legislation/biosecurity-act-2014/general-biosecurity-obligation accessed 10 June 2021

Table 11. Responsibility for invasive species management in Queensland under the Biosecurity Act 2014 (State of Queensland, 2020)

Biosecurity risk category set by the Act	Description	Primary responsibility for management	Primary management activities
Prohibited matter	Biosecurity matter (i.e., weeds and pest animals) that *are not present* in Queensland, but would have a 'significant adverse impact' on Queensland's triple bottom line; or	Queensland Government	Border controls by Queensland Government
Restricted matter	Biosecurity matter (i.e., weeds and pest animals) that *are present* in Queensland and have 'significant impact' on Queensland's triple bottom line.	Landowners (private, government, non-government, etc.)	Active day-to-day management by landowners

Queensland's local government authorities are tasked with planning relevant activities to manage invasive species at a local scale and to work with local communities to help them comply with the Act. The Act allows for local government authorities to establish and implement a local government biosecurity plan (Queensland Government (Department of Agriculture and Fisheries), 2016) that:

- sets strategies, activities and responsibilities for pest management at a local scale
- sets achievable objectives for the local community
- incorporates monitoring and evaluation mechanisms to determine the effectiveness of the plan
- informs regional planning processes on local management priorities.

Typically, local government biosecurity plans remain operational for 4–5 years' duration, with reviews undertaken after each annual operational period.

Instrumental to the development and implementation of each local government biosecurity plan, is the prioritisation of invasive species for management. Species prioritisation is undertaken within a multi-stakeholder environment based on a pre-defined prioritisation framework (Figure 21). Each invasive species is given a score based on its status (national alert list, state declaration); the level of risk it poses to public health and safety, as well as to the region's economic, social and environmental values; and the capacity for management (species' current extent, level of invasiveness and the feasibility of containment). The species' scores are ranked from the highest to lowest; species are then categorised into low, medium and high priority invasive species categories for subsequent on-ground management (Figure 21). On-ground management of high priority invasive species is undertaken in partnership with landholders and supported by a range of assistance programs.

Landholders, through the Act's GBO, have a responsibility to manage invasive species on their land. To assist landholders in meeting their GBO obligations, local governments, Natural Resource Management (NRM) groups and industry groups provide a range of incentive programs which include, among others:

- access to free/reduced fee control equipment
- access to free/reduced fee human resources to manage high-priority weed and pest animal infestations
- fee free biosecurity extension services and planning services
- grant programs
- herbicide rebates
- land rate subsidies for proactive management of weed and pest animal infestations.

Typically, assistance programs delivered by these organisations are designed to align with Commonwealth Government and Queensland Government NRM priorities and are often tailored towards voluntary adoption of industry-led best management practice (BMP) standards (Olvera-Garcia & Neil, 2020). Whilst there has been some research on the effectiveness of assistance programs and voluntary adoption of BMP in Queensland, much of the research literature has mainly focused on delivering water quality improvements in the Great Barrier Reef catchments (e.g., Dale et al. 2018; Hamman and Deane, 2018; Hasan et al. 2021; Kroon et al. 2016). Similar research on the effectiveness of assistance programs and the voluntary adoption of industry-led BMP for invasive species management at a landscape scale in Australia is needed (Jones et al. (2006) is one of the few examples).

Similar to fragmentation, weed and pest animal presence can be regarded as both a condition variable and as an environmental pressure (see Figure 18 and Section 5.5.2 for details on data sources and GIS processing).

Category	Attribute	Score			
		3	2	1	0
Status	National status	National alert list or national eradication program	Weed of National Significance (WoNS) or national feral animal list	Not scored	Not scored
	State declaration	Invasive prohibited matter	Invasive restricted matter or restricted matter - noxious fish	Not scored	Not scored
Potential impact	Environmental impact	Major impact on biodiversity and/or riparian areas	Moderate impact on biodiversity and/or riparian areas	Minor impact on biodiversity	No impact
	Social impact	Major risk to public health / safety (e.g. fatality) or amenity	Moderate risk to public health / safety / amenity	Minor annoyance	No impact
	Economic impact	Major threat to primary production, industry or transport	Moderate threat	Minor threat	No impact
Capacity to manage pest	Current / potential distribution	Localised with high potential to spread further in / beyond LGA	Widespread with moderate potential to spread further	Widespread with little risk of further spread	Not scored
	Invasiveness	Rapid dispersal mechanisms and high population growth rate	Moderate dispersal and population growth rate	Slow dispersal and population growth rate	Not scored
	Achievability	Population small and can be effectively contained / eradicated	Population large but can be effectively contained / reduced OR population small but no effective control	Population large and difficult to contain with current controls	Not scored

Priority	Score
Low	0-9
Medium	10-14
High	15+

Figure 21. Example of an invasive species prioritisation framework used by the Balonne Shire Council in the Balonne Shire Council Biosecurity Plan 2019–2024. Example demonstrates the ranking of invasive species based on the impact that the species has on the region's values, including environmental, social and economic impacts (Balonne Shire Council, 2019).

5.5.2 Invasive species: identification for inclusion in ecosystem accounts

Stage 1 – Identification of priority invasive species

In total, six local, state and national invasive species management frameworks (Table 12) were used to select priority invasive species for inclusion in the Mitchell catchment Ecosystem Accounts.

Table 12. Local, state and national management frameworks used for identification of priority weed and pest animal species in the Mitchell catchment. No regional frameworks were publicly available for assessment.

Management framework	Management scale	References
Carpentaria Shire Biosecurity Plan 2019	Local	carpentaria.qld.gov.au/homepage/65/biosecurity-plan
Cook Shire Council Local Area Biosecurity Plan	Local	cook.qld.gov.au/services/biosecurity/legislation/cook-shire-biosecurity-plan-2017-2021_v1-3_approved-signed.pdf/view
Mareeba Shire Community Biosecurity Plan 2020–2025	Local	msc.qld.gov.au/news/biosecurity-plan
Biosecurity Act 2014	State	legislation.qld.gov.au/view/html/inforce/current/act-2014-007
Weeds of National Significance list	National	weeds.org.au
Australian Government Threat Abatement Plans	National	environment.gov.au/biodiversity/threatened/threat-abatement-plans/approved

Within the six management frameworks in Table 12, a total of 40 invasive species were identified as priority species for the Mitchell catchment of which 33 were weed species[12] and 7 were pest animal species (Table 13).

[12] Buffel grass is not included as it is not listed as a priority species for management in any of these six management frameworks because it is considered to deliver a positive benefit to triple bottom line overall via its contribution to increasing cattle stocking density and growth rate.

Table 13. Priority weed and pest animal species for the Mitchell catchment, identified with reference to six local, state and national invasive species management frameworks.

Common name	Scientific name	Management framework			Form
		Local	State	National	
Priority weed species					
Asparagus fern	*Asparagus scandens*		✓	✓	Fern
Bellyache bush	*Jatropha gossypiifolia*	✓	✓	✓	Shrub
Broad leaf privet	*Ligustrum lucidum*	✓	✓		Tree
Cabomba	*Cabomba caroliniana*	✓	✓	✓	Aquatic plant
Camphor laurel	*Cinnamomum camphora*	✓	✓		Tree
Cat's claw creeper	*Macfadyena unguis-cati*	✓	✓	✓	Vine
Chinee apple	*Ziziphus mauritiana*	✓	✓		Tree
Chinese privet	*Ligustrum sinense*	✓	✓		Tree
Fireweed	*Senecio madagascariensis*		✓	✓	Forb
Gamba grass	*Andropogon gayanus*	✓	✓	✓	Grass
Giant sensitive plant	*Mimosa diplotricha*	✓	✓		Shrub
Hymenachne	*Hymenachne amplexicaulis*	✓	✓	✓	Aquatic plant
Koster's curse	*Clidemia hirta*	✓	✓		Shrub
Lantana	*Lantana camara*	✓	✓	✓	Shrub
Maderia vine	*Anredera cordifolia*	✓	✓	✓	Vine
Miconia	*Miconia calvescens, M. cionotricha, M. racemosa, M. nervosa*	✓	✓		Tree
Parkinsonia	*Parkinsonia aculeata*	✓	✓	✓	Tree
Parthenium	*Parthenium hysterophorus*	✓	✓	✓	Forb
Pond apple	*Annona glabra*	✓	✓	✓	Tree
Prickly acacia	*Vachellia nilotica*	✓	✓	✓	Tree
Prickly pear	*Opuntia spp. Other than O. ficus-indica*		✓	✓	Cactus
Rubber vine	*Cryptostegia grandiflora*	✓	✓	✓	Vine
Sagittaria	*Sagittaria platyphylla*		✓	✓	Aquatic plant
Salvinia	*Salvinia molesta*	✓	✓	✓	Aquatic plant
Siam weed	*Chromolaena odorata*	✓	✓		Shrub
Sicklepod	*Senna obtusifolia*	✓	✓		Shrub
Singapore daisy	*Sphagneticola trilobata*	✓	✓		Forb

Common name	Scientific name	Management framework			Form
		Local	State	National	
Sporobolus spp. *[13]		✓	✓		Grass
Thunbergia spp. *		✓	✓		Vine
Tobacco weed	*Elephantopus mollis*	✓	✓		Shrub
Water hyacinth	*Eichornia crassipes*	✓	✓	✓	Aquatic plant
Water lettuce	*Pistia stratiotes*	✓	✓		Aquatic plant
Yellow oleander	*Cascabela thevetia*	✓	✓		Shrub
Priority pest animal species					
Cane toad	*Rhinella marina*	✓		✓	Vertebrate pest
Feral cat	*Felis catus*	✓	✓	✓	Vertebrate pest
Feral deer	*Unknown*	✓	✓		Vertebrate pest
Feral horse	*Equus caballus*	✓	✓		Vertebrate pest
Feral pig	*Sus scrofa*	✓	✓	✓	Vertebrate pest
Rabbit	*Oryctolagus cuniculus*	✓	✓		Vertebrate pest
Wild dog	*Canis familiaris, C. familiaris dingo, C. lupus familiaris, C. lupus dingo*	✓	✓	✓	Vertebrate pest

[13] * Includes more than one species

Stage 2 – Priority invasive species spatial data set identification

Eight spatial datasets were identified that included spatial information on one or more priority invasive species:

- Annual Pest Distribution Survey 2008
- Annual Pest Distribution Survey 2009
- Annual Pest Distribution Survey 2011/12
- Annual Pest Distribution Survey 2013/14
- Pest Central – Weeds
- Pest Central – Animals
- Queensland Weed Distribution Current
- WildNet

Listings of priority invasive species in the Mitchell catchment within each spatial dataset is reported in Table 14. The species richness of all priority invasive species (weeds and pest animals) is mapped by species presence in 18.5 km × 18.5 km grid cell across the Mitchell catchment (Figure 22). The total area (in hectares) of each ecosystem type within which each priority invasive species has been reported to be present is calculated based on overlaps between the 18.5 km × 18.5 km invasive species presence grid cells and the underlying polygon mapping of ecosystem functional groups.

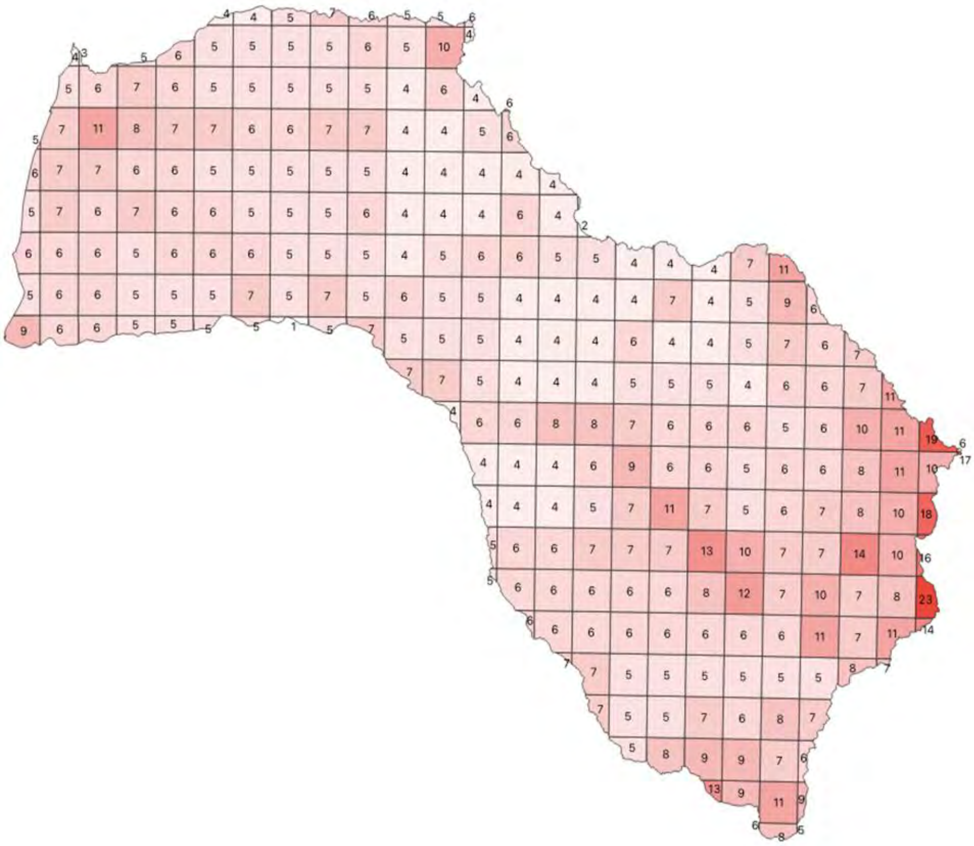

Figure 22. Total number of priority invasive species present across the Mitchell River catchment. Maximum number of total priority invasive species calculated by Pest Central, Annual Pest Distribution Surveys, Queensland Weed Distribution Current, WildNet and Atlas of Living Australia datasets, available on QSpatial. Each grid cell is 18.5 km × 18.5 km = 342.25 km^2.

Table 14. Priority invasive species occurrence in each pest or weed dataset.

	Asparagus fern	Bellyache bush	Broad leaf privet	Cabomba	Camphor laurel	Cats claw creeper	Chinee apple	Chinese privet	Fire weed	Gamba grass	Giant sensitive plant	Hymenachne	Koster's curse	Lantana	Maderia vine	Miconia	Parkinsonia	Parthenium	Pond apple	Prickly acacia	Prickly pears	Rubber vine	Sagittaria	Salvinia	Siam weed	Sicklepod	Singapore daisy	Sporobolus sp.	Thunbergia sp.	Tobacco weed	Water hyacinth	Water lettuce	Yellow oleander	Cane toad	Feral cat	Feral deer	Feral horse	Feral pig	Rabbit	Wild dog
APD survey						✓			✓	✓		✓								✓						✓		✓	✓		✓	✓				✓		✓		
APD survey	✓	✓		✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓			✓	✓	✓		✓	✓								
APD survey		✓				✓				✓		✓	✓	✓		✓		✓		✓		✓			✓	✓		✓	✓					✓		✓			✓	✓
APD survey		✓	✓	✓					✓	✓	✓		✓			✓	✓	✓		✓	✓			✓	✓			✓	✓		✓	✓			✓	✓	✓	✓	✓	✓
Pest Central		✓					✓					✓		✓			✓					✓			✓	✓		✓					✓					✓		✓

	Asparagus fern	Bellyache bush	Broad leaf privet	Cabomba	Camphor laurel	Cats claw creeper	Chinee apple	Chinese privet	Fire weed	Gamba grass	Giant sensitive plant	Hymenachne	Koster's curse	Lantana	Maderia vine	Miconia	Parkinsonia	Parthenium	Pond apple	Prickly acacia	Prickly pears	Rubber vine	Sagittaria	Salvinia	Siam weed	Sicklepod	Singapore daisy	Sporobolus sp.	Thunbergia sp.	Tobacco weed	Water hyacinth	Water lettuce	Yellow oleander	Cane toad	Feral cat	Feral deer	Feral horse	Feral pig	Rabbit	Wild dog
QLD Weed	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓								
WildNet/ALA		✓		✓			✓	✓		✓		✓	✓	✓				✓			✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓	✓

Table 14: continued

5.6 River disturbance

The type and intensity of catchment land uses can have major impacts on river condition. Point sources (e.g., discharges from sewage treatment plants, feedlots, refineries, aquaculture) and non-point sources (e.g., agricultural runoff, stormwater drains) of pollution can cause significant deteriorations in water quality and river condition. Human activities on land create disturbances in native ecosystems by disrupting the ecosystem's ability to maintain its structure, composition and function through time (United Nations Statistics Division, 2021, p.81). A pristine ecosystem condition is thus commonly associated with an undisturbed state of the environment. A large body of research has been undertaken to better understand the type and level of impacts of anthropogenic disturbances on ecosystem health (e.g., Arciszewski et al. 2021; Bunn et al. 2010; Das et al. 2021; Espinoza et al. 2021). Similarly, research effort has been directed towards identifying which condition indicators are more responsive to human-induced change within a relatively short time frame to facilitate prompt management response (e.g., Barton et al. 2020; Negus et al. 2020; Taner et al. 2019; Yassine et al. 2020).

Tracking and estimating the level of disturbance occurring in the environment is important for informing spatially targeted land management actions. For aquatic ecosystems, (Stein, Stein, & Nix, 2002) proposed a method to produce a spatially specific River Disturbance Index indicating levels of anthropogenic disturbance of 1.5 million Australian stream segments (a total length of over 3×10^6 km). The River Disturbance Index is based on a consistent characterisation of the entire river network in Australia and index values form a continuum from severely degraded (value at or near 1) to near-pristine or 'wild' (value at or near zero) (Stein et al. 2002). Stein et al's method utilises the following information as surrogate indicators of the extent of disturbance of natural river processes (Stein et al. 2002; p.2):

- intensity and extent of human activities in the catchment
- in-stream structures that alter flow regime.

The original source data (in 1988) detailed in Stein et al. (2002) was updated with (see Data Inventory):

- Catchment Scale Land Use Mapping for Australia (updated April 2009)
- Geodata TOPO 250K series from Geoscience Australia 2003
- Integrated Vegetation Cover 2009.

The updated River Disturbance Index values are available for download from the Australian Bureau of Meteorology website as a GIS spatial layer in the form of polylines and an associated look-up table (Environmental Stream Attributes V.1.1.1 August 2012) (see Data Inventory). Index values are provided for 1,396,648 stream segments of which 27,614 are within the Mitchell catchment. River Disturbance Index values were mapped and tabulated by ecosystem type for inclusion in the Ecosystem Pressures Account, as an ancillary account to the Condition Variable Account for the Mitchell catchment.

6. Ecosystem capacity

Ecosystem capacity provides the link between ecosystem assets and ecosystem services by aiming to quantify the link between an asset's extent and condition and its capacity to supply different ecosystem services (Figure 3). Ecosystem capacity is generally a function of the extent and condition of an ecosystem asset under current ecosystem management and ecosystem use. Ecosystem capacity also relates to the notion of sustainability and the level of ecosystem service the asset is called upon to supply. Lai et al. (2018) compare different definitions of ecosystem capacity from recent literature, reproduced here as Table 15. In general, capacity refers to the *maximum sustainable flow* of an ecosystem service that can be supplied from a given ecosystem asset in such a way that this use does not impair the ecosystem asset's ability to supply that ecosystem service, or other ecosystem services through time (Lars Hein et al. 2016; Lai et al. 2018; Schröter, Barton, Remme, & Hein, 2014).

Table 15. Summary of definitions of ecosystem capacity from selected published literature. Reproduced from Lai et al. (2018) p.54.

Reference	Definition of sustainability	Relation between capacity and actual ecosystem service use
Schröter *et al.* (2014)	Sustainability is not explicitly defined. In the examples given, the capacity flow of an ecosystem service is measured without considering the level of other ecosystem services.	Actual ecosystem service use can be lower or higher than the capacity.
Hein *et al.* (2015)	The sustainable ecosystem service flow is the maximum supply and use of an ecosystem service that does not lead to degradation in ecosystem condition.	Actual ecosystem service use can be lower or higher than the capacity
Hein *et al.* (2016)	The sustainable ecosystem service flow is the maximum ecosystem supply and use that does not negatively affect the future supply of the same or other ecosystem services from that ecosystem. The capacity indicator is measured for one ecosystem service, but sustainability needs to consider the ecosystem as a whole.	When actual ecosystem service use is lower than the sustainable flow, capacity equals actual ecosystem service flow; when actual ecosystem service use is higher than the sustainable flow, capacity equals the sustainable flow.
La Notte *et al.* (2017)	Ecosystem capacity is a stock that provides a sustainable flow of an ecosystem service. Sustainable flow is measured for a single ecosystem service.	Actual ecosystem service flow cannot be higher than the capacity, but it can be higher or lower than the sustainable flow.

Deriving a consistent measure of ecosystem asset capacity is challenging. Part of the challenge is to select indicators or attributes that respond to differing levels of delivery of each specific ecosystem service for the ecosystem asset concerned. This alone is a very complex undertaking. There is also an issue regarding whether the measure of capacity refers to the ecosystem type as a whole or to the capacity of a particular ecosystem asset of that ecosystem type to supply a targeted ecosystem service (La Notte et al. 2017). For these reasons, assessments of ecosystem capacity lie outside the scope of this study.

However, within Project 4.6, McMahon et al. (2022) explored potential use of the InVEST model (Sharp et al. 2020) to predict supply of the soil retention ecosystem service, knowing aspects of the condition of relevant ecosystem types within the Mitchell catchment (see Section 7.7.2). This is an important topic as, for regulating ecosystem services particularly, it is likely that modelling will be used to estimate ecosystem service supply – and thus modelling is also likely to be an important component in assessing the capacity of ecosystem assets to supply particular levels of ecosystem service(s) sustainably into the future under given management and socio-economic scenarios.

7. Ecosystem services in biophysical terms

7.1 Ecosystem services within SEEA EA

In the SEEA EA framing, humans derive *benefits* from ecosystem assets through their utilisation of the ecosystem services those assets supply (Figure 3)(). *Ecosystem services* are thus regarded as the *contributions* that ecosystems make to supply or production of *benefits* in the form of goods and services that contribute to human well-being (United Nations et al. 2021; Section 6.2, p.121). These *benefits* can be delivered as goods and services that are purchased in markets (e.g., food, water, energy, clothing, shelter, recreation etc.). These types of benefits *are* included *within the production boundary* of the United Nations' System of National Accounts (SNA) (European Commission et al. 2009) and are termed '*SNA benefits*' in SEEA EA terminology (United Nations et al. 2021; paragraph 6.17, p.122). However, ecosystems can also contribute to supply of benefits in the form of goods and services that sit *outside the production boundary* of SNA and are thus *not* reported in the SNA (e.g., global climate regulation, flood protection, water quality filtration) (M Eigenraam & Obst, 2018; Obst & Eigenraam, 2017; Obst et al. 2016). These are termed '*non-SNA benefits*' in SEEA EA terminology (United Nations et al. 2021; paragraph 6.18, p.123). Ecosystems' *contributions to* supply of SNA benefits and non-SNA benefits should *both* be reported in *supply and use tables* in Ecosystem Accounts.

Viewing ecosystem services as ecosystems' *contributions* to SNA benefits and non-SNA benefits, the ecosystem services that should be reported in supply and use tables in Ecosystem Accounts are those that have the most *direct link* between ecosystem assets and the benefits provided to human beneficiaries (i.e., businesses, governments and households – collectively termed 'economic units'). This means that only *final* ecosystem service flows are reported in SEEA EA supply and use tables i.e., those services from ecosystem assets that contribute to SNA or non-SNA benefits that are *delivered* to economic units (United Nations et al. 2021; paragraph 6.24, p.124). In appropriate contexts, provisioning, regulating, and cultural ecosystem services can generally be regarded as final services, whereas supporting services cannot.

Intermediate services are supporting services that provide inter-ecosystem flows, and thus are 'used' by other ecosystem assets (La Notte and Rhodes, 2020; United Nations et al. 2021; paragraph 6.26, p.124). Although intermediate services do not make their way into the SEEA EA supply and use tables, compiling data and information on intermediate services is still a useful exercise that can enhance understanding of the nature of interconnected ecosystem assets and the ecosystem services they supply. Furthermore, some of these data and related information can potentially be used as indicators for evaluating ecosystem condition and/or as indicators of an ecosystem's capacity to supply a particular ecosystem service flow.

There is a fundamental misalignment between human interactions with ecosystems as conceptualised in the SEEA Ecosystem Accounts and the way in which Indigenous Traditional Owners conceptualise such interactions. Human - ecosystem interactions are conceptualised as being 'transactional' and 'linear' in SEEA Ecosystem Accounts (i.e., ecosystem services *from* ecosystems *to* people). In contrast, Indigenous Traditional Owners' regard interactions with Country as 'relational' and 'reciprocal'; Traditional Owners have responsibilities to care for Country in order for Country to continue to contribute benefits to current and future generations human society.

Whist acknowledging conceptual misalignments, it is important to recognise that Ecosystem Accounts provide a potential opportunity for documenting and reporting the contribution of Indigenous Traditional Owners in managing Country in ways that enhance supply of many ecosystem services that benefit human society. Ecosystem Accounts also have the potential to track changes in ecosystem condition and the multiple pressures that affect condition. This could be particularly relevant for Indigenous communities because of their strong relationship with and dependence upon Country.

More broadly, considerations of morality, history, and scientific accuracy make it essential for Ecosystem Accounts to consider how Indigeneity is made visible in such accounts. Colonial contexts like Australia usefully highlight how an incredibly long extended history of Indigenous management of landscapes has been disrupted by much shorter periods of subsequent aggressive colonisation, with consequences for landscape change, human management, and ecosystem service provision. Sensitivity to Indigeneity provides more nuanced understanding of the assumptions underlying estimates of baseline conditions, the ways in which actors and their activities are rendered (in)visible in accounting practices, and the potential future options for improvement in asset condition and service provision. As such, Ecosystem Accounting research in Australia's north – where Indigenous populations have high levels of reliance on ecosystem assets – could thus be very informative, nationally and internationally.

SEEA EA suggest that a 'logic chain' can be helpful for clarifying how ecosystem services contribute to the supply of benefits to human well-being (United Nations et al. 2021; Section 6.2.6 and Figure 6.2, p.127). An example logic chain for supply of air purification services is shown in Figure 23 below.

Ecosystem service	Relevant ecosystem types in the Mitchell (e.g.,)	Factors determining supply		Factors determining use	Physical metric for ecosystem service supply	Benefits	Users and beneficiaries
		Ecological	Societal				
Air filtration service	T1.1 Tropical subtropical lowland rainforests T4.4 Temperate woodlands	Type and condition of ecosystem assets e.g., woody vegetation cover, ambient pollutant concentration	Location, type and volume of air pollutants released	Location and number of people and buildings adversely affected by air-borne pollutants	Types and quantities of pollutants absorbed during air filtration e.g., PM10, PM2.5	Reduced concentrations of air pollutants leading to improved human health and reduced damage to buildings	Households and businesses in down-wind locations

Figure 23. Logic chain surrounding ecosystem assets' contributions to supply of air filtration benefits (Drawing on Figure 6.2, p.127 in United Nations et al. (2021)).

The logic chain approach helps to clarify the following key points regarding how ecosystem services are defined and reported in supply and use tables in Ecosystem Accounts:

All ecosystem services are regarded as being supplied by ecosystem assets of particular ecosystem types (either singly, or – as in the example in Figure 23

Ecosystem service	Relevant ecosystem types in the Mitchell (e.g.,)	Factors determining supply		Factors determining use	Physical metric for ecosystem service supply	Benefits	Users and beneficiaries
		Ecological	Societal				
Air filtration service	T1.1 Tropical subtropical lowland rainforests T4.4 Temperate woodlands	Type and condition of ecosystem assets e.g., woody vegetation cover, ambient pollutant concentration	Location, type and volume of air pollutants released	Location and number of people and buildings adversely affected by air-borne pollutants	Types and quantities of pollutants absorbed during air filtration e.g., PM10, PM2.5	Reduced concentrations of air pollutants leading to improved human health and reduced damage to buildings	Households and businesses in down-wind locations

Figure 23 – in combination).

The quantity of the ecosystem service *supplied* can be influenced by ecological factors (e.g., the biotic, abiotic and/or landscape condition of the ecosystem asset(s) supplying the service) and by societal factors. Relevant societal factors could include availability of produced assets (e.g., fishing boats or tractors) and labour to contribute alongside the ecosystem service as inputs to a *joint production process*, as if often the case for provisioning ecosystem service flows[14]. For regulating ecosystem service flows, societal factors such as pollutant concentrations (as in the Figure 23 example) can affect ecosystem service supply. Thus, if the air contains negligible concentrations of the pollutants that could be filtered out by forests and woodlands then these ecosystem assets would not be considered to be supplying air filtration services.

The quantity of the ecosystem service *used* will be influenced by how individuals and economic units (households, businesses, government) engage with the ecosystem service flow. If the *use* of the ecosystem service flow *cannot be described and quantified* then it should *not* be reported in the supply and use tables in Ecosystem Accounts. Thus, if no households or businesses are located down-wind of forests and woodlands that filter out PM10 particulates then there are no 'users' of the air filtration ecosystem service and no supply or use of the service will be reported in the supply and use tables in Ecosystem Accounts. This has important consequences for reporting of supply and use of ecosystem services from a sparsely populated region like the Mitchell catchment; where no users are present, no ecosystem service flows will be reported – unless the service flow concerned delivers a public good benefit from collective use (e.g., the global climate regulation service). See Section 7.5.1 and Section 8.3.1 for further details on this point.

Where possible, it is helpful to identify a physical metric for measurement that can be used as a proxy for *biophysical* supply of the relevant ecosystem service (e.g., tonnes of PM2.5

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[14] The term *joint production process* indicates that the production process that produces a benefit (e.g., the harvest of barramundi from the Mitchell estuary by the commercial barramundi fishery) uses inputs sourced from ecosystem assets (provision of natural fish biomass as an ecosystem service from the estuary), *jointly* with inputs sourced as produced assets from the manufactured capital stock (fishing boats and fishing gear), intermediate inputs for other economic sectors (e.g., diesel), and labour (fishers – and their knowledge) as an input from stocks of human and intellectual capital.

pollutant filtered out by forests and woodlands, tonnes of native grazing fodder consumed by cattle on rangelands).

Ecosystem Accounts focus on the contribution that ecosystems make to the delivery of benefits to human society. As a starting point for quantifying ecosystems' contributions, it is helpful to consider how the benefit as a whole can be quantified. Where relevant, benefits that accrue to society will typically be quantified *inclusive* of the contributions from ecosystems, produced assets, intermediate (manufactured) inputs, and labour to joint production processes.

Figure 24 shows stylised models for identifying final ecosystem service flows for example provisioning, regulating and cultural services, consistent with the logic chain approach illustrated in Figure 23 and the points raised above.

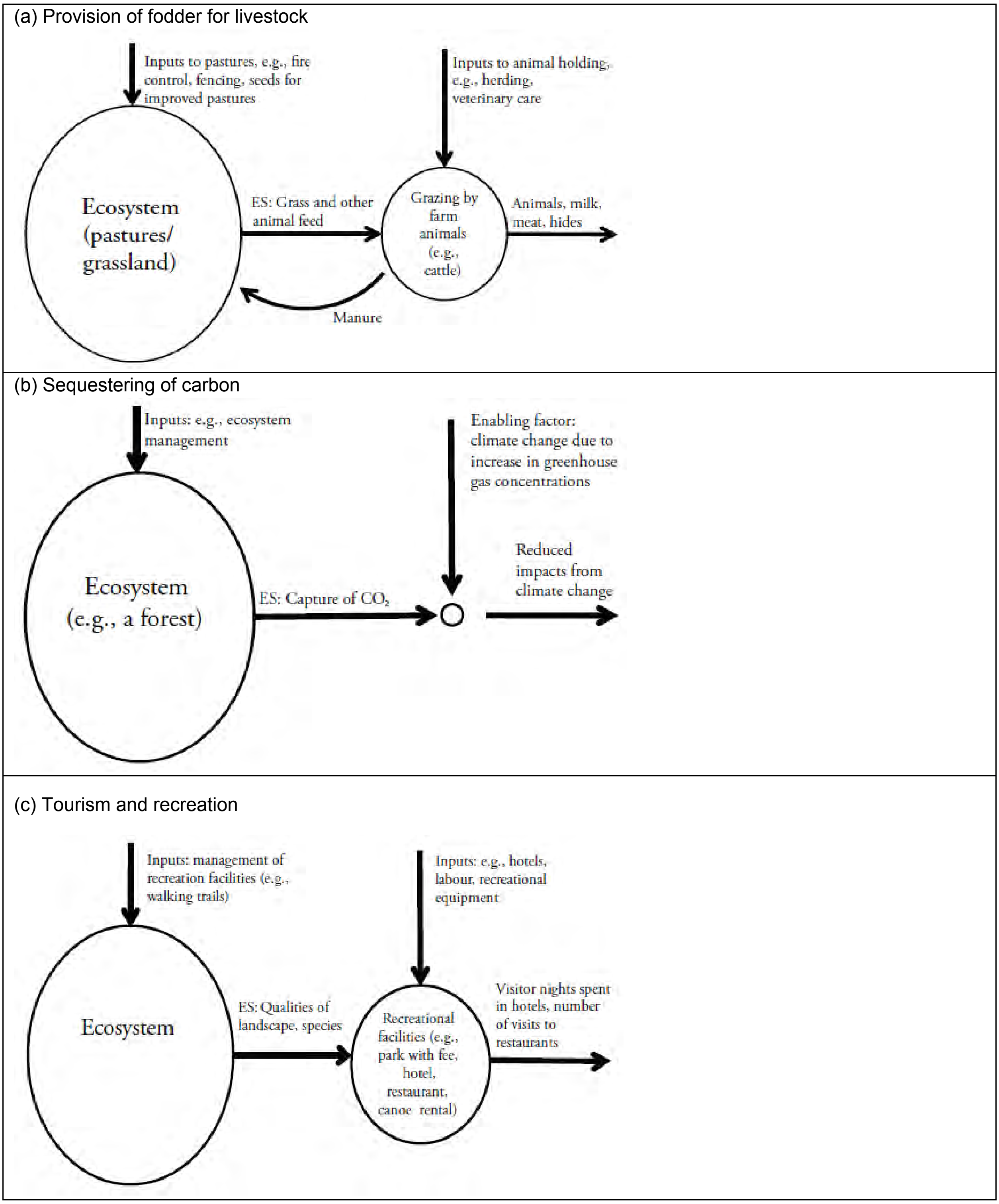

Figure 24. Stylised models for identifying and measuring selected final biophysical flows of a provisioning ecosystem service (fodder for livestock), a regulating ecosystem service (carbon sequestration as a component of global climate regulation) and a cultural ecosystem service (tourism and recreation). Source: United Nations, European Union, et al. (2014, p.62–69).

It is important to note that *ecosystem services* as defined above and reported in Ecosystem Accounts are themselves necessarily *outside the production boundary* of SNA (United Nations et al. 2021; paragraph 619, p.123). This is true even though ecosystem services *can* *contribute* to the production of SNA benefits[15] (which by definition will be represented within the production boundary of SNA). The positioning of Ecosystem Accounts and the SNA is quite distinct. Ecosystem Accounts report supply and use of ecosystem services (in both biophysical and monetary terms) as ecosystems' contributions to delivery of SNA benefits and non-SNA benefits. These ecosystem services are, by definition, ***outside*** the production boundary of the SNA. They may, however, represent ecosystems' ***contributions*** to *benefits* that ***are*** reported in SNA ('SNA benefits'). The SNA reports these SNA-***benefits***, and does so in monetary terms ($).

Consider the $ value of sales revenues from catches in the commercial barramundi fishery operating in the Mitchell estuary (Figure 25). This $ value will be reported in SNA as an 'SNA benefit' from the commercial fishery[16].

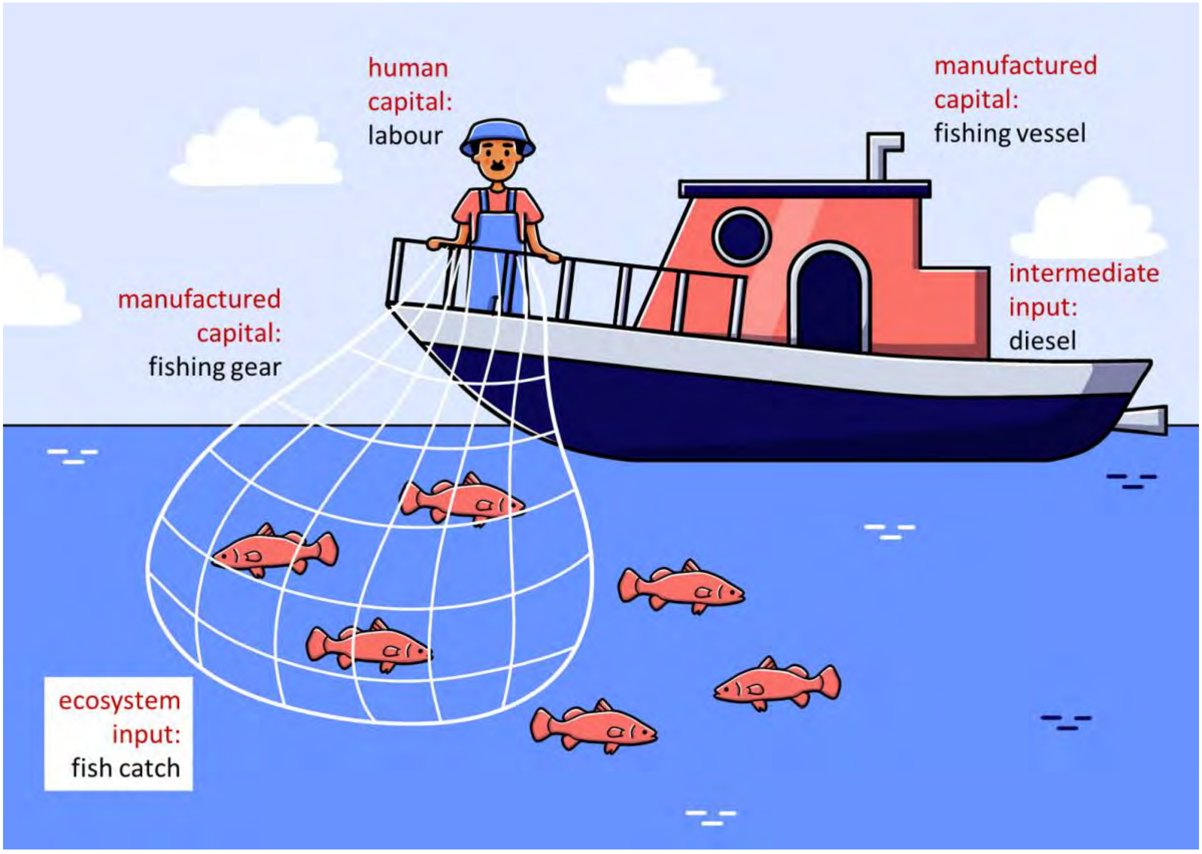

Figure 25. Biophysical inputs to the joint production process in the commercial barramundi fishery operating in the Mitchell estuary. Inputs are contributed from natural capital (the catch of harvestable barramundi as an ecosystem service from the Mitchell estuary), manufactured capital (fishing boat and fishing gear), intermediate inputs (diesel from other industrial sectors), and human and intellectual capital (fishers' labour and knowledge).

Ecosystems contribute to the reported SNA benefit (i.e., the sales revenue from the barramundi catch) by supplying a stock of barramundi from which the commercial harvest can be taken. The harvested barramundi from this stock ***are*** the *contribution* (i.e., the

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[15] Typically, this will be the case for provisioning ecosystem services which contribute as inputs to joint production processes in primary industries such as farming, fishing, and forestry, or for businesses that offer recreation services in natural landscapes (e.g., guided nature tours, recreational fishing charters etc).
[16] Albeit aggregated into the total sales revenues of the wild capture fisheries sector.

ecosystem service) that the ecosystem[17] supplies as an input to the *joint production process* that is the commercial barramundi fishery. In *biophysical* terms, this ecosystem service would be reported in the Ecosystem Account's *biophysical* supply and use tables as the tonnage of barramundi caught in a particular year.

When reported in the Ecosystem Account's supply and use tables in *monetary* terms, the *monetary value* of the *ecosystem's contribution* to the joint production process that generates the SNA benefit (the sales revenue from the barramundi catch) has to be *separated out* from the monetary value of contributions to joint production from produced assets (e.g., fishing boats and fishing gear), intermediate inputs (e.g., diesel), and labour. This needs to be done carefully and consistently if the monetary value of the ecosystem contribution (i.e., the monetary value of the ecosystem service) is to be determined clearly.

Where final ecosystem services are inputs to a joint production process, the value attributed to those ecosystem services in monetary supply and use tables will necessarily be *less than* the overall monetary value of the benefit provided to society – to acknowledge the value contributions from other inputs to the joint production process (United Nations et al. 2021; paragraph 7.21, p.163). This would *not* be the case, however, if the benefit to society is delivered via a natural 'production process' that requires *no* inputs other than those from natural capital stocks in the form of ecosystem assets, e.g., the global climate regulation service provided by sequestration and storage of carbon in natural forests and woodlands. In such cases it is highly likely that the societal benefit concerned is a non-SNA benefit i.e., the value of that benefit is *not* recorded in the SNA. Monetary valuation of ecosystem services for inclusion in monetary supply and use tables for the Mitchell catchment Ecosystem Account is described further in Chapter 8.

By accounting separately and distinctly for ecosystem services (in both biophysical and monetary terms), as ecosystems' contributions to SNA benefits and non-SNA benefits, an important intention and outcome of Ecosystem Accounting is to make the contributions of ecosystem assets to human well-being more explicit (Remme et al. 2015). Before the advent of Ecosystem Accounting the contributions of ecosystem assets to human well-being were absent, or at best opaque, in national accounts.

7.2 Treatment of non-use values in SEEA EA

Economics generally adopts an anthropocentric, instrumental value paradigm[18]. Within this paradigm, the suite of values that human society derives from and associates with the natural environment can be conceptualised using the Total Economic Value (TEV)

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[17] In the supply and use tables in Ecosystem Accounts, supply of an ecosystem service is assigned to the ecosystem type in which the ecosystem service *delivers* its contribution to the joint production process. In this example this is the Mitchell estuary and the immediate coastal zone.

[18] Economics adopts an *anthropocentric perspective* and an *instrumental value* paradigm in which ecosystems and the environment are valued because of the multiple benefits they supply to human society. These benefits can be categorised using Pearce and Turners' Total Economic Value Framework (Pearce & Turner, 1990). Alternative paradigms for valuing ecosystems and the environment include the *intrinsic value* paradigm (in which environment has value irrespective of whether or not it delivers benefits to human society – see Batavia and Nelson (2017) for a recent review) and the *relational value* paradigm (in which values emerge from relationships and responsibilities between entities – here 'environment' and human society – see Chan et al. (2016)).

framework (Pearce & Turner, 1990). TEV distinguishes between two main categories of value: *use values* and *non-use values*. Under TEV, use values arise when benefits to human society are generated through direct (e.g., harvesting food and resources, hiking in a forest, breathing clean air) or indirect (e.g., flood mitigation provided by water regulation in natural environments) *interactions* between people and the environment. These *use values* (direct and indirect) are the focus for ecosystem services in SEEA EA, as ecosystems' contributions to societal benefits (United Nations et al. 2021; paragraph 6.69, p.136). In contrast, *non-use values* are values that people ascribe to particular ecosystems even though they do not receive any benefits *from interactions* (either directly or indirectly) *with* those ecosystems. Examples of non-use values include the benefit that an individual may ascribe to the continued existence of a wetland ecosystem in the Mitchell in good ecological condition, perhaps because they consider it important to pass that ecosystem on in good condition to future generations ('bequest value'), or because they consider it important that such pristine ecosystems continue to exist amidst multiple pressures and threats ('existence value').

These non-use values may be of considerable importance and the benefits associated with them may be of considerable value (e.g., Ahtiainen et al. 2014; Carson, 2000; He et al. 2017; Lindhjem et al. 2015). However, because non-use values arise in the absence of any interactions (direct or indirect) between economic units and the ecosystems concerned, SEEA EA does not consider that a *'transaction'* has taken place to generate the resulting benefit. Consequently, since *'transaction'* or *'exchange'* is the basis for recording supply and use of ecosystem services in SEEA EA, non-use values are *not* recorded in the supply and use tables in SEEA Environmental Accounts (United Nations et al. 2021; paragraph 6.72, p.137).

Noting that non-use values evidence important connections between human society and the environment, the category of 'ecosystem and species appreciation' is included in the SEEA EA 'Reference List of Ecosystem Services' to allow data to be reported that can be directly associated with non-use values – for example the presence or abundance of iconic species (United Nations et al. 2021; Table 6.3, p.134; paragraph 6.73, p.137). Recording of these potential proxies for non-use values may be policy relevant, and in some situations could potentially be used to support a case for undertaking separate estimation of non-use values, outside SEEA Ecosystem Accounts.

7.3 Classification of ecosystem services

For consistency, ecosystem services have been classified using the following classification systems:

- Common International Classification of Ecosystem Services (CICES) Version 5.1 (Haines-Young & Potschin, 2018)
- Final Ecosystem Goods and Services – Classification System (FEGS-CS) (Landers & Nahlik, 2013)
- National Ecosystem Service Classification System (NESCS) (United States Environmental Protection Agency (US EPA), 2015).

CICES was developed to support measurement and accounting of ecosystem services for SEEA. It classifies *final* ecosystem services into three main groups following a 'hierarchical structure based on ecosystem service types, types of uses and types of flows' (United Nations, 2017, p.81; Haines-Young and Potschin, 2018, p.iv):

- provisioning of material and energy for human needs
- regulating and maintaining the environment for human wellbeing
- non-material characteristics of ecosystems affecting physical and mental states of individuals.

FEGS-CS and NESCS both follow systemic approaches to ecosystem service classification and are alternatives to CICES. As described in United Nations (2017, p.81–82), FEGS-CS's approach is to link types of ecosystems to types of use-beneficiaries, whilst the NESCS is based on a nested hierarchical structure linking types of ecosystems, types of ecological endpoints, types of uses and types of beneficiaries. CICES can also be used as a reference classification for translations between ecosystem service classification schemes such as those used by the Millennium Ecosystem Assessment (MEA) and The Economics of Ecosystems and Biodiversity (TEEB) (Haines-Young & Potschin, 2018). Correspondences between CICES v4.3 classes, MEA typology and TEEB typology are provided in Czúcz et al. (2018).

7.4 Ecosystem services in ecosystem accounts for the Mitchell catchment

The SEEA EA Final Draft (Version 5) (2021; Table 6.3, p.126) provides a reference list of selected ecosystem services grouped into provisioning, regulating and cultural ecosystem service categories. The SEEA EA Version 5 list uses similar ecosystem service sub-categorisations as CICES but is somewhat less detailed in terms of its ecosystem service sub-definitions. In Project 4.6 we estimate supply and use of the ecosystem services shown in Table 16 from the SEEA EA Final Draft (Version 5) reference list from ecosystems in the Mitchell:

Table 16. Ecosystem services in the supply and use accounts for the Mitchell River catchment (from the reference list of ecosystem services in SEEA EA Final Draft (Version 5) (2021; Table 6.3, p.126)). Grey cells indicate that an ecosystem type is known to, or likely to, supply the nominated ecosystem service, but the biophysical quantity of supply cannot be established using a method recommended by SEEA EA (White cover version) (United Nations et al. 2021).

Ecosystem service category	Ecosystem service	Description	Context
Provisioning services			
Biomass provisioning	Crop provisioning services	Crop provisioning services are the ecosystem contributions to the growth of cultivated plants that are harvested by economic units. This is a final ecosystem service.	Crop provisioning services supplied to growth of cultivated crops in the Mareeba-Dimbulah Irrigation Area.
Biomass provisioning	Grazed biomass provisioning services	Grazed biomass provisioning services are the ecosystem contributions to the growth of grazed biomass that is an input to the growth of cultivated livestock. In this context it is a final ecosystem service.	Grazed biomass provisioning services supplied to livestock on cattle stations throughout the Mitchell catchment.
Biomass provisioning	Wild fish biomass provisioning services	Wild fish biomass provisioning services are the ecosystem contributions to the growth of fish that are captured in uncultivated production contexts by economic units. This is a final ecosystem service	Barramundi caught by the commercial barramundi fishery operating in the estuaries of the Mitchell River delta and in the coastal zone. Barramundi and other species caught for household consumption by Indigenous households in Kowanyama and by recreational fishers throughout the catchment.

Table 16 (continued).

Ecosystem service category	Ecosystem service	Description	Context
Provisioning services (continued)			
Biomass provisioning	Wild animals, plants and other biomass provisioning services	Wild animals, plants and other biomass provisioning services are the ecosystem contributions to the growth of wild animals, plants and other biomass that are captured and harvested in uncultivated production contexts by economic units for various uses (but excludes wild fish that are included in previous class). This is a final ecosystem service	Wild animals, plants and other biomass resources harvested for household consumption by Indigenous households in Kowanyama. Wild animals (particularly feral pigs) harvested by recreational hunters in the catchment.
Water supply: irrigation	From surface sources	Water supply services reflect the combined ecosystem contributions of water flow regulation, water purification, and other ecosystem services to the supply of water of appropriate quality for irrigation usage. This is a final ecosystem service.	Water supply for the Mareeba-Dimbulah irrigation system is supplied via Sunwater (sunwater.com.au) from an offtake in Lake Tinaroo *in the neighbouring Barron catchment*. In the far east of the Irrigation Area, smaller volumes are abstracted from weirs on the Walsh River and Eureka Creek (both within the Mitchell catchment).
	From groundwater		Water supply for irrigated cropping around Julatten, Leadingham Creek, Petford and Watsonville is extracted from groundwater bores.

Table 16 (continued).

Ecosystem service category	Ecosystem service	Description	Context
Provisioning services (continued)			
Water supply: household consumption	From surface sources	Water supply services reflect the combined ecosystem contributions of water flow regulation, water purification, and other ecosystem services to the supply of water of appropriate quality for household consumption, after appropriate treatment and processing. This is a final ecosystem service.	The raw water supply for the towns of Dimbulah and Mutchilba is drawn from the Sunwater irrigation channel, before being filtered and chlorinated to potable standard for household supply. A reticulated non-potable water supply for 97 residential properties in Mt Molloy is abstracted from Hunter Creek. (Morris Hamill, Manager of Water & Waste, Mareeba Shire Council: pers. comm.).
	From groundwater		Raw water for Chillagoe and Kowanyama is extracted from ground water aquifers, before being filtered (at Chillagoe) and chlorinated (at both locations) to potable standard for household supply. (Chillagoe: Morris Hamill, Manager of Water & Waste, Mareeba Shire Council: pers. comm.; Kowanyama: Kowanyama Aboriginal Shire Council, (2012))

Table 16 (continued).

Ecosystem service category	Ecosystem service	Description	Context
Regulating and maintenance services			
Global climate regulation services		Global climate regulation services are ecosystem contributions to the regulation of the chemical composition of the atmosphere and oceans that affect global climate through the accumulation and retention of carbon and other GHGs (e.g., methane) in ecosystems and the ability of ecosystems to remove carbon from the atmosphere. This is a final ecosystem service.	Carbon retention within ecosystem assets in the catchment. (Carbon retention in biomass (above and below ground) and soils reported separately). Avoided carbon release (i.e., net carbon sequestration) via savanna fire burn management across the catchment.
Soil and sediment retention services	Soil erosion control services	Soil erosion control services are the ecosystem contributions, particularly the stabilising effects of vegetation, that reduce the loss of soil (and sediment). This may be recorded as a final or intermediate service.	Soil erosion control service supplied by vegetated ecosystems in the catchment
Cultural services			
Recreation-related services	Recreation-related services	Recreation-related services are the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that enable people to use and enjoy the environment through direct, in-situ, physical and experiential interactions with the environment. This includes services to both locals and non-locals (i.e., visitors, including tourists). Recreation-related services may also be supplied to those undertaking recreational fishing and hunting. This is a final ecosystem service.	Recreation-related outdoor experiences undertaken by visitors and local residents throughout the catchment.

Table 16 (continued).

Ecosystem service category	Ecosystem service	Description	Context
Cultural services (continued)			
Spiritual, artistic and symbolic services	Spiritual, artistic and symbolic services	Spiritual artistic and symbolic services are ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that are recognised by people for their cultural, historical, aesthetic, sacred or religious significance. These services may underpin people's cultural identity and may inspire people to express themselves through various artistic media. This is a final ecosystem service.	The contribution of place and Country to cultural identity of Indigenous and non-Indigenous residents throughout the catchment.
Other cultural services	Other cultural services		A range of cultural ecosystem services associated with caring for Country.

7.5 Supply and use tables in biophysical terms

SEEA EA supply and use tables report ecosystem service flows *from* each ecosystem type *to* users i.e., businesses in specified sectors of the production economy and other beneficiaries (households and government), following 'logic chains' as illustrated in

Ecosystem service	Relevant ecosystem types in the Mitchell (e.g.,)	Factors determining supply Ecological	 Societal	Factors determining use	Physical metric for ecosystem service supply	Benefits	Users and beneficiaries
Air filtration service	T1.1 Tropical subtropical lowland rainforests T4.4 Temperate woodlands	Type and condition of ecosystem assets e.g., woody vegetation cover, ambient pollutant concentration	Location, type and volume of air pollutants released	Location and number of people and buildings adversely affected by air-borne pollutants	Types and quantities of pollutants absorbed during air filtration e.g., PM10, PM2.5	Reduced concentrations of air pollutants leading to improved human health and reduced damage to buildings	Households and businesses in down-wind locations

Figure 23. In *biophysical* supply and use tables, these flows are expressed in biophysical terms and users are categorised following the format of the Australian System of National Accounts (ASNA), i.e., categorisation of economic sectors follows the ASNA classification and codes. Table 17 shows an example of a simplified biophysical ecosystem service supply and use account that is aligned with the ASNA. The beneficiaries of ecosystem services are broadly grouped into businesses (categorised by ASNA code), households, government and 'global'.

Table 17. Example layout of an ecosystem service biophysical supply (from ecosystem types (ET)) and use (by sectors of the economy) account in respective units of biophysical measurement.

Ecosystem services (in relevant units of measurement & categorised according to CICES)	ET1	ET2	SUIC 010 Agriculture	SUIC 110 Food product manufacturing	House-hold final demand	Govern-ment	Global	Total
Supply								
Provisioning service 1								
Provisioning service 2								
Provisioning service 3								

Regulating service 1								
Regulating service 2								
Cultural service 1								
Cultural service 2								
Use								
Provisioning service 1								
Provisioning service 2								
Regulating service 1								
Regulating service 2								
Cultural service 1								
Cultural service 2								

Note: SUIC: Supply Use Industry Classification. Adapted from Australian Bureau of Statistics' Supply and Use Tables, 2016–17 (cat. no. 5217) (Australian Bureau of Statistics, 2018a) and (United Nations, European Union, *et al.* 2014, Table 3.4 on p.55).

7.5.1 *Supply of final ecosystem services by ecosystem types and their use by economic units*

Supply and use tables in Ecosystem Accounts record the supply of final ecosystem services by ecosystem types and their use by economic units. In some cases, this is straightforward, particularly where a final service is supplied by a single ecosystem type as an input to a joint production process operated by a clearly defined economic unit that generates an SNA benefit (e.g., supply of the catch of harvestable barramundi from the Mitchell estuary to the commercial barramundi fishery operating in the Mitchell catch zone). In this instance it is feasible to exclude other users[19]. From an economic perspective this ecosystem service

[19] Other catches from the same barramundi stock by other economic units (e.g., for direct consumption by Indigenous households in Kowanyama, or direct consumption by recreational fishers (S. Jackson, Finn, & Scheepers, 2014c; Scheepers & Jackson, 2012b)) would contribute as ecosystem service inputs to the generation of additional non-SNA benefits to the users concerned. If relevant data were available, the supply of these ecosystem service inputs would also be reported in supply and use tables in biophysical and monetary terms.

would be considered as a common pool resource because it is rival and excludable among a defined group of users (via licenced access to the commercial fishery)[20]. In contrast, other ecosystem services – typically those that deliver non-SNA benefits (e.g., global climate regulation) – contribute to the generation of benefits that can be realised simultaneously by multiple economic units, without one unit's (e.g., household's) access to that benefit reducing the benefit that is available for another unit (e.g., another household). Ecosystem services with these characteristics would be considered pure public goods because they are non-rival and non-excludable. 'Users' of ecosystem services with these public good characteristics are treated in Ecosystem Accounts in the same way that 'collective consumption' services are treated in the SNA (United Nations et al. 2021; 7.32, p.165). Where the ecosystem service contributes to a collective non-SNA benefit, the highest level of government in the ecosystem accounting area concerned is considered to be the service user on behalf of society as a whole.

The SEEA EA principles described in the preceding subsections are applied in the following subsections to quantify supply and use of ecosystem services in biophysical terms in biophysical supply and use tables in the Ecosystem Accounts for the Mitchell catchment as contributions to the production of benefits to human society.

7.6 Estimating biophysical service supply: provisioning services

This project seeks to quantify supply of six provisioning services from ecosystems in the Mitchell catchment (Table 16). Four of these are categorised as 'biomass provisioning services' in the Reference List of Ecosystem Services in the SEEA EA (White cover version) of September 2021; the fifth and sixth are 'water supply' for use by irrigated agriculture and households (United Nations et al. 2021; Table 6.3, p.131). The SEEA EA (White cover version) provides a detailed description of how supply should be estimated in biophysical terms for biomass provisioning services (United Nations et al. 2021; Section 6.4.1 and paragraph 6.55) and for water supply (United Nations et al. 2021; Section 6.4.2 and paragraph 6.57). The following paragraphs draw from these descriptions.

SEEA EA recognises that biomass from ecosystems is sourced and used by human society in different ways and for a wide range of purposes. In some situations, biomass is harvested directly by the final consumer (e.g., for direct household consumption); however, the majority of provisioning biomass is harvested, accessed or grown by economic units (e.g., farms, fishing businesses, forestry operations). In all these cases, biomass provisioning services are combined with additional human-sourced inputs in some form of joint production process to produce a benefit to society. For these economic units, this benefit will be recorded in monetary terms in the SNA as an SNA-benefit (e.g., $ revenues from farm production, fish catches or timber extraction etc.). Human-sourced inputs to these joint production processes can typically be considered as flows from underlying stocks of human-sourced capitals such as harvesting machinery or fishing boats and fishing gear (from the stock of manufactured

[20] A common pool resource is rival in use and excludable for a defined group of users (Ostrom, Burger, Field, Norgaard, & Policansky, 1999). A resource is rival if one user's consumption of that resource reduces the quantity available for other users. A resource is excludable if access to the resource can feasibly be restricted to a set of individuals. For a common pool resource, access is restricted to a defined pool of users – in this instance holders of the relevant commercial fishing licence.

capital), labour and know-how (from stocks of human and intellectual capitals), and other consumables such as diesel, artificial fertiliser etc. (purchased as intermediate inputs from other sectors of the production economy). The biomass provisioning services reported in SEEA EA are ecosystems' contributions to these joint production processes. These ecosystem services can be regarded as flows from the stock of natural capital resident in ecosystem assets.

Following the approach taken in the SNA, SEEA EA distinguishes between *natural* and *cultivated* production, based on the extent to which an economic unit manages the growth of the harvested biomass. The various biomass provisioning services can thus be positioned along a *natural* to *cultivated* continuum, across which the ecosystem contribution to the joint production process varies from high to low (Figure 26). The four biomass provisioning services for which quantification is sought in the Mitchell catchment span much of this continuum.

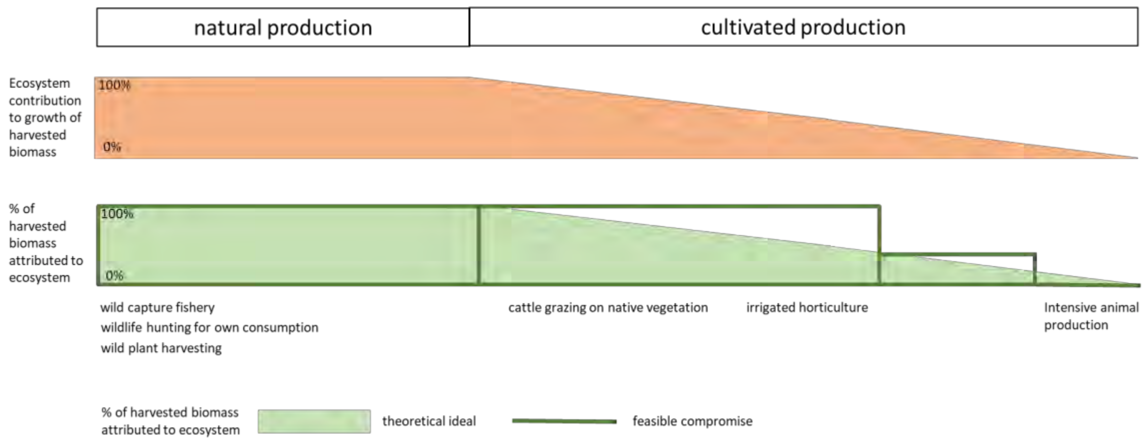

Figure 26. Ecosystem contributions to biomass provisioning services in natural and cultivated production (drawing on SEEA EA (2021; Section 6.4 and paragraphs 6.55 and 6.66)).

From a SEEA EA perspective, harvesting of plants and other biomass resources for household consumption by Indigenous households in Kowanyama and elsewhere in the catchment, hunting of feral pigs and other native and feral animals for food, catching fish for household consumption, and harvesting of wild barramundi by the commercial barramundi fishery that operates in the Mitchell estuary can all be classified as *natural production*. This is because, in all these instances, the economic unit (business or household) that undertakes the harvesting has not managed or controlled the biomass growth[21]. For natural production, SEEA EA indicates that the full amount of the harvested biomass should be regarded as the ecosystem's contribution to the societal benefit that results (i.e., the ecosystem service that contributes to the value assigned to the produced output) (United Nations et al. 2021; paragraph 6.84, p.139). Consequently, where relevant data are available, the full amount of

[21] SEEA's instrumental value paradigm is at odds here with the relational value paradigm and the 'Circle of Reciprocity' concept (Comberti et al. 2015) regarding Traditional Owners' caring for Country. In the relational value paradigm and the Circle of Reciprocity, Custodians' caring for Country is a necessary prerequisite for Country providing Custodians with biomass resources for harvesting.

biomass harvested by the commercial barramundi fishery[22], and the full amount of biomass harvested through hunting of feral pigs, other wild animals, fish, birds' eggs, crabs and shellfish for household consumption should be recorded in the Ecosystem Account's biophysical supply and use tables as the quantity of the biomass provisioning service supplied by relevant ecosystem type(s) in these natural production contexts.

In *cultivated production* contexts, the objective within SEEA EA is to clearly identify *the ecosystem's contribution* to the biomass provisioning service flow, and then to attribute that contribution to the ecosystem(s) that supply it (United Nations et al. 2021; paragraph 6.87, p.140). This approach recognises that, even within cultivated production, the ecosystem contribution can vary considerably. Ideally, the ecosystem contribution to biomass provisioning should be identified explicitly; however, where this is not feasible, the *gross biomass harvested* can be used a proxy measure (United Nations et al. 2021; paragraph 6.55, p.134). This is the approach adopted here when quantifying supply of crop provisioning services to the growth of cultivated crops and horticultural products in the Mareeba-Dimbulah Irrigation Area in supply and use tables in the Ecosystem Account for the Mitchell.

When considering provisioning ecosystem services to livestock production, the direct interaction between livestock and the ecosystem(s) should be the focus for estimating the ecosystem contribution (United Nations et al. 2021; paragraph 6.56, p.134). From this perspective, provision of grazed biomass will typically be the key ecosystem service input (i.e., ecosystem-sourced input) to the joint production process of cultivated livestock production. In the extensive livestock production system operated on cattle stations in the Mitchell, grazing biomass is produced almost entirely from natural growth on unimproved pastures (within the 'grazing native vegetation' land use designation of QLUMP land use mapping) (Chilcott et al. 2020; Section 1.3). In this context, SEEA EA recommends that the grazed fodder offtake should be reported as a measure of the grazed biomass provisioning service input to livestock production, and no separate livestock provisioning service should be recorded in the supply and use accounts (United Nations et al. 2021; paragraph 6.95, p.141).

Following these guidelines, the approaches adopted to quantify biophysical supply of provisioning services in the Mitchell catchment are illustrated in Figure 26. Data sources used for biophysical quantification of the corresponding ecosystem service flows in biophysical supply and use tables are described for each provisioning biomass service flow in the following subsections.

7.6.1 Wild fish provisioning service as an input to the commercial wild capture barramundi fishery

A commercial wild capture barramundi fishery operates in the Mitchell estuary/delta and its immediate coastal zone, as a sub-component of the Gulf of Carpentaria Inshore Fin Fish Fishery (GoCIFFF). The barramundi fishery operates under the N3 symbol attached to a

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[22] SEEA EA (White cover version) indicates that the full amount of harvested biomass should be recorded as the ecosystem contribution from the fishery – including bycatch and discards (United Nations et al. 2021; paragraph 6.84, p.139). Data were not available on bycatch and discards from the commercial barramundi fishery operating in Mitchell estuary catch zone, so here we regard the total reported catch as the ecosystem contribution.

Queensland primary commercial fishing licence[23] in the GoCIFFF. The N3 symbol allows operation in a gill net fishery that targets primarily barramundi in estuarine and foreshore waters[24] of the Gulf of Carpentaria from Slade Point near the tip of Cape York Peninsula westward to the Queensland – Northern Territory border (State of Queensland Department of Agriculture and Fisheries, 2019a). Management of the N3 fishery uses mainly input controls to restrict catch and effort (State of Queensland Department of Agriculture and Fisheries, 2019; Appendix B). Only a limited number of N3 symbols are available (85 N3 symbols were available in 2017), the barramundi fishery is closed from midday on 7 October to midday on 1 February every year, a size limit of 14 m is imposed on the main vessel[25], there are restrictions on net mesh size (between 160 mm and 215 mm when fishing in rivers and creeks), and total net length per symbol (no more than 120 m per net, and no more than 360 m in total net length), and minimum (60 cm) and maximum (120 cm) size restrictions are in place on the fish caught.

The majority of barramundi fishing effort on the N3 symbol is concentrated in creeks, rivers and nearshore waters. Catch and effort data for boats operating in the N3 commercial barramundi fishery are collected by the Queensland Department of Agriculture and Fisheries. These data are available at 30 nautical mile grid square resolution in the publicly accessible QFISH data base (qfish.fisheries.qld.gov.au). Catches of barramundi in QFISH 30- nautical mile grid squares AB12, AB13 and AC14 are considered Mitchell River-sourced fish (pers. comm. J. Robins, Queensland Department of Agriculture and Fisheries). Combined barramundi catches from these three grid squares over the years 2010–2017 inclusive, averaged 143 tonnes, with a mean of between 6.3 and 9.5 licences operating in each of the grid cells over the same period.

Following the recommendations of the SEEA EA (White cover version) (United Nations et al. 2021; Section 6.4 and paragraphs 6.55 and 6.89) – as illustrated in Figure 26 – we report this 143 tonne average annual catch from the N3 commercial barramundi fishery in the biophysical supply and use tables as the harvested biomass that is supplied to the commercial barramundi fishery (the user) by the Mitchell estuary BVG class[26] (the supplier).

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[23] Queensland primary commercial fishing licence: business.qld.gov.au/industries/farms-fishing-forestry/fisheries/licences/primary-licence . Fisheries symbols: business.qld.gov.au/industries/farms-fishing-forestry/fisheries/licences/fisheries-symbols
Applicable area – N3 net fishery symbol in Gulf of Carpentaria Inshore Fin Fish Fishery: daf.qld.gov.au/__data/assets/pdf_file/0020/62606/n3-goc-fishery.pdf

[24] The N3 symbol permits fishing out to seven nautical miles from the shoreline, with some modifications to net-related licence conditions (State of Queensland Department of Agriculture and Fisheries, 2019; Appendix B).

[25] A main boat typically operates with two smaller dinghies ('tenders') to set gill nets in estuarine channels and subsequently retrieve the nets to harvest the catch.

[26] SEEA EA (White cover version) (2021; paragraph 6.97, p.141) indicates that supply of a wild fish catch should be attributed to the ecosystem in which that catch is extracted (the 'estuary' BVG in the case of barramundi harvested by the N3 commercial fishery), but also recognises that multiple ecosystems may have contributed to the growth of barramundi biomass at different stages during the fish life cycle.

7.6.2 Ecosystem contributions to wildlife hunting and fishing and wild plant harvesting for household consumption

Anecdotally, feral pig hunting is undertaken in the Mitchell catchment, with putative joint objectives of feral animal control and hunting for home consumption. Recreational fishing for home consumption is also practiced for a wide range of species, with barramundi *(Lates calcarifer)* and Mitchell River prawns *(Macrobrachium rosenbergii)* noted as favoured target species (Gill, 2020; p.24). Household survey-based data collection under the TRaCK Program on the harvesting of animals and plants for consumption by Indigenous households in Kowanyama reported that a total of 36 aquatic-related species were utilised (Jackson et al. 2014b; Appendix A). Several species of fish, turtles, crustaceans, shellfish, birds, reptiles, and plants were hunted or collected by Indigenous households for household consumption. The same study used the replacement cost method to estimate the value that surveyed Indigenous households in Kowanyama derived from these bush foods, and found that the imputed value of bush foods comprised almost 23% of the total value of food consumed (S. Jackson et al. 2014a).

The foregoing suggests that it is likely that wildlife hunting and wild plant harvesting are important and valuable activities for some Indigenous and non-Indigenous households in the catchment. However, aside from the TRaCK studies undertaken by Jackson et al. (2014b and 2012) in Kowanyama, and some additional data along similar lines compiled from Kowanyama in this project (see Chapter 11), the authors are unaware of any data that provide catchment-wide quantification of animal and plant biomass harvested for home consumption, or that detail the locations at which biomass harvesting takes place. However, it is clear that aquatic and wetland ecosystems will be the focus for many of these harvesting activities (i.e., the *water* and *estuary* BVGs, together with *palustrine wetlands* (TF1.2 and TF1.4), and *brackish tidal systems* (MFT1.2 and MFT 1.3)). The *palustrine wetlands* and *coastal saltmarshes and reedbeds* are also likely to be prime locations for feral pig hunting – particularly during the dry season – as these ecosystems provide the waterbodies the pigs require to regulate their body temperature during hot weather as well as providing them with food sources. Pig hunting also occurs in woodland ecosystem types (particularly T1.1 and T3.1) in localities adjacent to farms that offer high food availability (e.g., bananas, sugar cane).

However, given the absence of catchment-wide data on biomass harvested and harvesting locations, whilst ‘wildlife hunting and fishing’ and ‘wild plant harvesting’ are retained as line items in the supply and use tables for the Mitchell catchment, it is not possible currently to report the total biomass of individual species harvested, or to identify which ecosystem types have supplied these service flows. These remain opportunities for further research.

7.6.3 Grazed biomass provisioning for cattle grazing on native vegetation

Extensive cattle grazing, mainly on ‘unimproved’ native pastures, is the major land use across the Northern Gulf NRM Region and the Mitchell catchment (Figure 27) (Ash et al. 2018; Bowen, Chudleigh, Rolfe, & English, 2019; Chilcott et al. 2020). Native tropical (C_4) pastures, oversown in some areas with legume species that are well adapted to low fertility soils (e.g., Stylosanthes group), provide the predominant forage input from these grazing lands (Bowen et al. 2019; Section 3.1.1). Seasonal and inter-annual variation in rainfall are the main determinants of pasture growth and quality. Crude protein input and dry matter digestibility levels are low for much of the year due to the lengthy dry season across much of the Mitchell catchment (Bowen et al. 2019; Section 3.1.2). Most of the native pastures in the Mitchell are classified as providing moderate to low grazing resource (in the context of the Northern Gulf NRM Region) (Bowen et al. 2019; Figure 2, p.26, drawing on Shaw et al. (2007)), and as delivering low productivity (in the context of cattle grazing across Queensland as a whole) (McLennan et al. 2020; Map 2, p.23 – drawing on Bray et al.(2015)). Bowen et al. note that graziers in the Northern Gulf Region face considerable profitability challenges, partly due to the low land productivity, and this leads to pressures to run high stocking rates that may exacerbate ongoing decline in land condition (Bowen et al. 2019; Section 3.1.3, p.30). Weed invasion and loss of perennial pasture species are cited as key indicators of condition decline on more fertile soils, and thickening of native woodland is cited as an indicator of grazing condition decline on less fertile land areas (Bowen et al. 2019; Section 3.1.3, p.30).

Figure 27. Extensive cattle grazing in the Northern Gulf region. Photo: Graeme Curwen.

Recently revised daily energy intake requirements and corresponding daily pasture dry matter offtake requirements, suggest that a representative pasture dry matter grazing offtake for cattle grazing on native pastures in the Mitchell is 8.5 kg dry matter per adult equivalent (AE)[27] per day (McLennan et al. 2020; Table 2, p.26). In their report on beef production systems in the Northern Gulf Region, Bowen et al. (2019) report cattle numbers, herd

[27] The adult equivalent (AE) methodology is used to calculate equivalent energy intakes and – when coupled with dry matter intake constants for relevant categories of grazing land – to calculate dry matter pasture offtakes for cattle of different species, sex, age and weight (McLennan et al. 2020).

structure, and a cattle heads to AE ratio for a representative beef enterprise in the Northern Gulf. The cattle head to AE ratio reported by Bowen et al. is 1.308 : 1 (Bowen et al. 2019; Table 7, p.33). The stocking rate on Bowen et al.'s representative enterprise (12 ha/AE) closely matches the stocking rates reported by Ash et al. (2018) for representative beef enterprises at Highbury and Dunbar in the Mitchell (12 and 13 ha/AE, respectively) (Ash et al. 2018; Table 2-3, p.15). Consequently, the herd structure and cattle heads to AE ratio reported for Bowen et al's representative Northern Gulf enterprise are also taken to be appropriate for extensive grazing enterprises in the Mitchell that are reliant predominantly on native vegetation.

Meat and Livestock Australia (MLA) provide representative cattle numbers for all regions across Australia (beefcentral.com). MLA's estimates for cattle numbers in the Mitchell[28] for the 12 months commencing June 2010, June 2015, June 2017 and June 2018 averaged 178,384 head (maximum 198,609 head in 12 months commencing June 2010, minimum 160,811 head in 12 months commencing June 2015). Assuming the same herd structure and ratio of cattle heads to AE ratio as Bowen et al's Northern Gulf enterprise across the entire Mitchell herd, the total AE for the Mitchell catchment for the average 178,284 head total cattle herd is 136,351 AE. At McLennan et al's indicative pasture dry matter grazing offtake of 8.5 kg dry matter per AE per day, an indicative total annual dry matter offtake from native grazing land in the Mitchell is thus approximately 423,000 tonnes per year.

In line with the recommendation of the SEEA EA (White cover version) that the ecosystem contribution to the joint production process of livestock grazing is the focus for reporting (United Nations et al. 2021; paragraph 6.95, p.141), this total annual grazed biomass of 423,000 tonnes is reported as the biophysical supply of grazed biomass services in the ecosystem service supply table for the Mitchell.

For the purposes of compiling supply and use tables in Ecosystem Accounts for the Mitchell, extensive cattle grazing is taken to occur across the 'Grazing Native Vegetation' land use in the QLUMP mapping (Figure 28). Biophysical supply of the grazed biomass service by ecosystem type in the ecosystem service supply table for the Mitchell is estimated by distributing the total estimated annual biomass offtake across IUCN ecosystem types within the QLUMP Grazing Native Vegetation land use in proportion their area of overlap. Following this approach, more than 96% of the grazing biomass supplied into the beef livestock sector in the Mitchell catchment is attributed as being sourced from three ecosystem types (T4.2 *pyric tussock savanna* (80%), TF1.2 *subtropical-temperate forested wetlands* (9%), and T4.3 *hummock savannas* (7%)).

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[28] Cattle numbers in the Mitchell calculated from MLA estimates by area-weighted intersection between the Mitchell catchment and MLA's reporting regions (Northern Gulf and Cape York for 2011 and 2015, and Northern Gulf and Cooperative Management Area for 2018 and 2019).

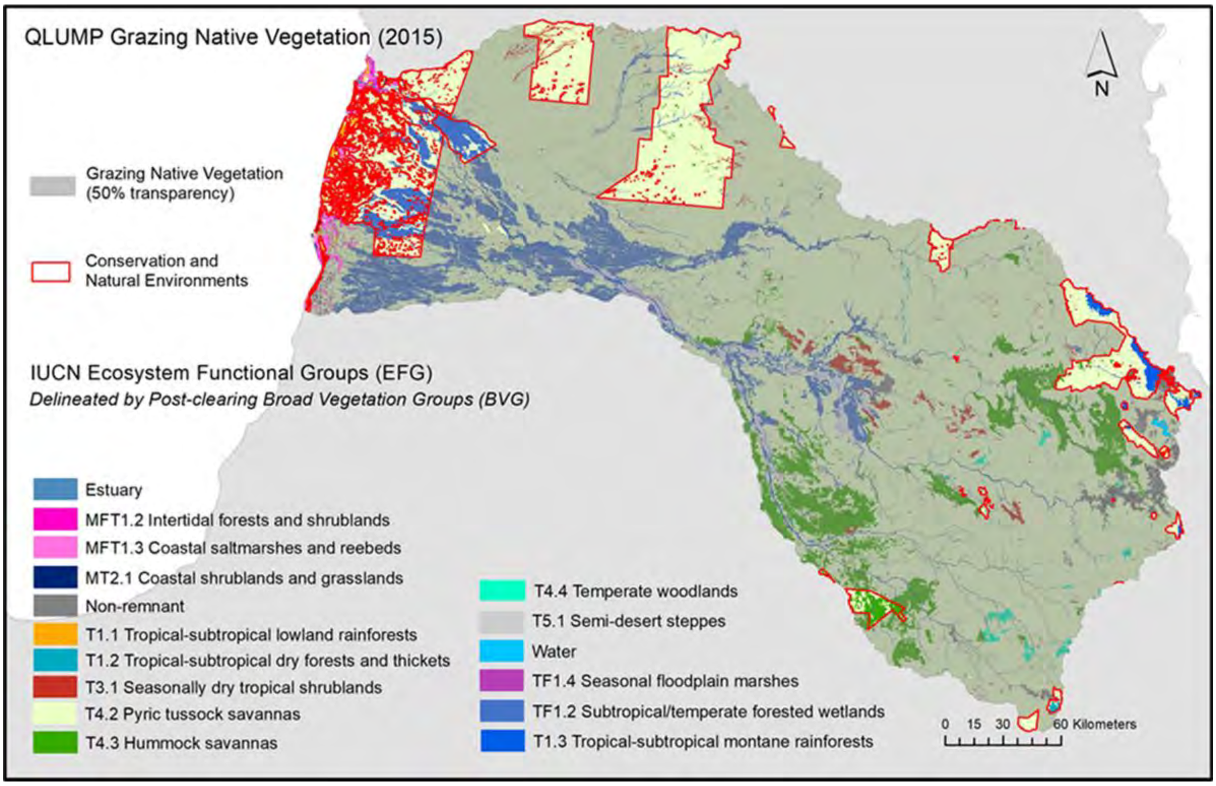

Figure 28. Spatial extent of grazing native vegetation land use in 2015, overlaid on ecosystem types (IUCN GET Ecosystem Functional Groups) in the Mitchell catchment.

7.6.4 Crop provisioning services for horticulture and cropping

Within the Non-remnant Broad Vegetation Group in the Mitchell catchment are approximately 21,500 ha categorised as the following irrigated QLUMP (2015) Secondary-level Land Use Classifications: irrigated cropping (c.15,300 ha), irrigated perennial horticulture (c. 5,800 ha), and irrigated seasonal horticulture (c. 400 ha). These land uses are primarily located in that part of the Mareeba-Dimbulah Irrigation Area that falls within the Mitchell catchment, and in small areas of irrigated tree crop production in the vicinities of Julatten, Leadingham Creek, Petford and Watsonville (University of New England: Applied Agricultural Remote Sensing Centre, 2022).

Under SEEA EA, ecosystems' contributions to horticulture and cropping production are regarded as a final ecosystem service and can be recorded in the biophysical supply and use tables in the Mitchell Ecosystem Account. In this instance, the joint production process of irrigated agriculture sits well towards the 'cultivated production' end of the natural to cultivated production spectrum (Figure 26) as many of the inputs required are purchased by the farm business as 'intermediate inputs' from other sectors of the production economy (e.g., fertiliser, irrigation water, agro-chemicals), or are contributed directly by the farm business itself (e.g., capital investments in farm machinery and packing facilities, labour for land preparation, crop husbandry and harvesting). Nevertheless, ecosystems still contribute inputs to irrigated crop production in the form of soil water, soil nutrients, trace minerals etc.. SEEA EA enables these inputs to be recognised in biophysical supply and use tables within Ecosystem Accounts either as separate services (e.g., nutrient supply, water supply, pollination (where relevant) etc.) or, when representation as separate services is not feasible, by recording the total biomass harvested as a proxy (United Nations et al. 2021; paragraphs 6.87 and 6.89, p.139–140). Here we use the latter approach.

The main irrigated crops cultivated in the Mitchell catchment are (by area grown and by gross revenue) sugarcane (9,195 ha), mangoes (2,005 ha), avocados (1,686 ha), citrus (1,052 ha), and bananas (165 ha) – all primarily in the Mareeba-Dimbulah Irrigation Area[29]. Using the average yields (tonnes/ha) for mango, avocado, citrus and banana from the 2019 Agricultural Profile for the Atherton Tablelands (State of Queensland Department of Agriculture and Fisheries, 2019b), and the average of the sugarcane yields reported in the Tablelands Agricultural Profiles for 2010 and 2015[30] (State of Queensland Department of Agriculture and Fisheries, 2010, 2015), the total biomasses of these five irrigated crops harvested in the Mitchell catchment are approximately: sugarcane (861,649 tonnes), mangoes (19,646 tonnes), avocados (17,392 tonnes), citrus (9,109 tonnes), and bananas (4,481 tonnes). As recommended in the SEEA EA (White cover version) (United Nations et al. 2021; paragraphs 6.87 and 6.89, p.139–140), these quantities are entered into the biophysical supply and use accounts for the Mitchell catchment as 'crop provisioning services', with the Non-remnant Broad Vegetation Group as the supply source and cropping and horticulture components within the agriculture sector as the user.

7.6.5 Water supply services

Consistent with SEEA EA's emphasis on regarding ecosystem services as 'ecosystems' contributions to anthropogenic benefits' (United Nations et al. 2021; Section 6.2, p.121), when considering water utilised in ecological and economic contexts, SEEA EA's focus is on ecosystems' contributions to the quantity and/or quality of water supply (United Nations et al. 2021; Section 6.4.2, p.142) . SEEA EA (White cover version) recommends that in situations where the individual contributions of services such as water flow regulation and water purification from ecosystem assets cannot be determined separately, a combined ecosystem service termed 'water supply' can be reported as a proxy (United Nations et al. 2021; paragraph 6.57 and Section 6.4.2). In these circumstances, the volume of water abstracted can be regarded as a final ecosystem service and reported as a proxy for the ecosystem contributions (United Nations et al. 2021; Section 6.4.2, paragraph 6.103, p.143). This is the approach adopted here. We consider water supply for irrigation and water supply for potable residential use separately as follows:

7.6.6 Water supply: irrigation

Irrigation water supplied by Sunwater for the Mareeba-Dimbulah Irrigation Area is sourced predominantly from Lake Tinaroo in the neighbouring Barron River catchment via a supply channel running from Tinaroo Falls Dam (sunwater.com.au/schemes/mareeba-dimbulah). In the far west of the Irrigation Area, smaller volumes are abstracted from weirs on the Walsh

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[29] Area of mango, avocado, citrus and banana derived from 2018-2021 remote sensing imagery by the Applied Agricultural Remote Sensing Centre, University of New England (une.edu.au/research/research-centres-institutes/applied-agricultural-remote-sensing-centre). Area of sugarcane derived from QLUMP 2015 mapping via the 'irrigated sugar' land use class. Indicative gross revenues from the Tablelands Agricultural Profile 2019 (State of Queensland Department of Agriculture and Fisheries, 2019b)

[30] The Tablelands Agricultural Profile 2019 does not provide data on sugarcane, but the 2015 and 2010 Profiles do.

River and Eureka Creek (both within the Mitchell catchment). Small areas of irrigated cropping around Julatten, Leadingham Creek, Petford and Watsonville are supplied from groundwater bores.

Overall, ecosystems within the Mitchell catchment do not make a major contribution to the quantity or quality of the water supply utilised for irrigated cropping. Water supply services for irrigated cropping in the Mareeba-Dimbulah Irrigation Area are thus recorded as **imports** (from the neighbouring Barron catchment) in the supply and use tables in the Mitchell's Ecosystem Accounts[31]. The water supply volume imported from the Barron catchment to service irrigated cropping in the Mitchell catchment's portion of the Mareeba-Dimbulah Irrigation Area is estimated to be in direct proportion to the percentage of the Mareeba-Dimbulah Irrigation Area's tree cropping that falls within the Mitchell catchment (52.4%) (determined from QLUMP 2015 spatial mapping). Using Sunwater's FY2019–20 data on the total volume of irrigation water delivered to the Mareeba-Dimbulah Irrigation Area (125,530 ML) (sunwater.com.au/water-data/report-statistics), the estimated water volume imported from the Barron catchment to service irrigated cropping in the Mitchell catchment's portion of the Mareeba-Dimbulah Irrigation Area is 65,833 ML.

The volumes of groundwater supplied to support the small areas of irrigated cropping around Julatten, Leadingham Creek, Petford and Watsonville are estimated knowing the areas of citrus, mango and banana cropping at each location from remote sensing imagery supplied by the Applied Agricultural Remote Sensing Centre, University of New England (une.edu.au/research/research-centres-institutes/applied-agricultural-remote-sensing-centre), together with the median irrigation water requirements (ML/ha) quoted by Ash et al. (2018; Table 5-8, p.79) for citrus (lime), mango and banana cropping in the vicinity of Mareeba. The resulting estimated total volume of groundwater supplied is 572 ML.

7.6.7 Water supply: potable water for residential use

The raw water supply for the town of Dimbulah and neighbouring Mutchilba is drawn from the Sunwater irrigation channel, before being filtered and chlorinated to potable standard for household supply (Morris Hamill, Manager of Water & Waste, Mareeba Shire Council: pers. comm.). Mareeba Shire Council report that during calendar year 2020 a total of 112.8 ML of potable water was supplied to 194 residential properties and 56 non-residential properties in Dimbulah (Mareeba Shire Council, 2020). This volume is recorded as 'water supply for residential use' **imported** from the Barron catchment in the biophysical supply and use tables in the Mitchell's Ecosystem Accounts.

Raw water for the towns of Chillagoe and Kowanyama is extracted from groundwater bores, before being filtered and chlorinated (Chillagoe) or chlorinated (Kowanyama) for reticulated household supply. Mareeba Shire Council report that during calendar year 2020 a total of 61.8 ML of potable water was supplied to 108 residential properties and 27 non-residential properties in Chillagoe (Mareeba Shire Council, 2020). Kowanyama Aboriginal Shire Council report that during calendar year 2012 a total of 328.5 ML of potable water was supplied for use by the Kowanyama community (population 944, 288 private dwellings (Australian Bureau

[31] The volume of water abstracted for these agricultural uses should also be recorded in the physical supply and use tables that accompany the water account that is compiled under the SEEA – Central Framework guidelines (SEEA-CF) (United Nations et al. 2012).

of Statistics, n.d.)) (Kowanyama Aboriginal Shire Council, 2012). Mareeba Shire Council also report that during calendar year 2020 a total of 63.7 ML was abstracted from Hunter Creek for a reticulated, non-potable water supply for 97 residential properties and 18 non-residential properties in Mt Molloy (Mareeba Shire Council, 2020). Water supply services for household use in these communities are reported as final ecosystem services sourced from surface waters or groundwater, appropriately, and used by households, in the biophysical supply and use tables in the Mitchell's Ecosystem Accounts.

7.7 Estimating biophysical service supply of regulating services

The SEEA EA (White cover version) lists 21 regulating and maintenance services in its reference list of ecosystem services (United Nations et al. 2021; Table 6.3, p.131–134). However, as noted in the introductory description in this section, in accordance with SEEA EA (White cover version) paragraph 6.42, p.128, if a 'user' in the form of an economic unit (i.e., a business, household or government) cannot be identified for an ecosystem service then that service should ***not*** be listed in the supply and use tables in the Ecosystem Account. This requirement makes it challenging to include regulating ecosystem services in supply and use tables for the Mitchell Ecosystem Account, given the very sparse population density across most of the catchment (Figure 11). Thus, although ecosystems undoubtedly contribute to, for example, air filtration and water flow regulation in the Mitchell, the absence of significant concentrations of air-borne pollutants in the vicinity of residential areas and a lack of major residential areas that are prone to flooding in the catchment make it difficult to conclusively identify 'users' as the beneficiaries of these – or most other – regulating ecosystem services. Consequently, in the supply and use tables we only list two regulating services provided by ecosystem assets in the Mitchell:

Global climate regulation services (in the form of carbon sequestration and carbon storage) – for which the national government are regarded as a proxy user for the public good benefit that this regulating service delivers to the global population (United Nations et al. 2021; paragraph 6.20 iii, p.123, Appendix 6.1, p.155), and

Soil and sediment retention service – for which cattle grazing businesses within the agricultural livestock sector are considered the user, benefitting from the reduction in soil erosion that vegetated ecosystems supply on the properties they own or manage.

Biophysical supply of these services was determined as described in the following subsections.

7.7.1 Global climate regulation services

The Reference List of ecosystem services in the SEEA EA (White cover version) describes global climate regulation services as being ecosystems' contributions to reducing the concentrations of greenhouse gases in the atmosphere by the sequestration of carbon from the atmosphere and its storage (i.e., retention) in ecosystems (United Nations et al. 2021; Section 6.4.3). Carbon sequestration and storage provided by ecosystems are regarded in SEEA EA as mechanisms that, within a given accounting period, contribute to supply of global climate regulation as a final ecosystem service. Global climate regulation services are of a public good nature in that they deliver non-rival and non-excludable benefits to the global population, on whose behalf the government are regarded as a proxy user (United Nations et al. 2021; paragraph 6.20 iii, p.123, Appendix 6.1, p.155).

Carbon plays a central role in many ecosystem processes, and changes in carbon stock are influenced by multiple economic activities. For example, components of the carbon cycle in the atmosphere (e.g., CO_2 in gas form), ocean (dissolved CO_2), geosphere (e.g., carbon in fossil fuels), and the biosphere (e.g., carbon in soil, in above- and below-ground biomass, and in dead biomass) either contribute to carbon in products within the economy or are receptors for carbon emissions from economic activities (United Nations et al. 2021; Section 13.4.3, p.285–288).

The component of the carbon cycle of interest to SEEA Ecosystem Accounting is carbon in the biosphere. Human activity influences the stock of carbon in the biosphere primarily through land use conversion or by affecting the magnitude, frequency or intensity of extreme events, such as fires, which lead to carbon release. Historically, human activity has had a major impact on the carbon cycle, and the scientific consensus is that this impact is changing the ability of the atmosphere to regulate climate (Masson-Delmotte et al. 2021). A stable climate underpins the proper functioning of society, and therefore the global climate regulation ecosystem service is likely to be one of the most valuable ecosystem services supplied by natural ecosystems.

This section:

- describes how biosphere carbon stocks stored in ecosystems within the Mitchell catchment were quantified to determine which carbon pools within which ecosystems are providing the greatest carbon retention service
- reports from which ecosystem types carbon sequestration projects in the Mitchell catchment have contributed carbon sequestration under the Australian Government's Emissions Reduction Fund (ERF)[32]. Carbon sequestration (via avoided carbon release) from savanna fireburn management in the Mitchell catchment utilises Indigenous Traditional Owners' expertise to supply this important contribution to global climate regulation service.

Estimating stored carbon stocks in the biosphere

Of the four biosphere carbon stocks mentioned above, data were available relating to carbon storage in above-ground and below-ground biomass, and as soil carbon. To the authors' knowledge, data on dead/decaying biomass in the Mitchell catchment's ecosystems are not available.

Above- and below-ground carbon pools

Above- and below-ground carbon densities (in Mg/ha) were derived from Spawn et al. (2020b). Spawn et al. used vegetation-specific remotely sensed data on percentage tree cover and landcover to derive estimates of above- and below-ground carbon densities in the year 2010 at 300-metre resolution. These carbon densities were combined with the polygon-derived areal extent of each ecosystem type in the Mitchell to estimate the total stocks of above- and below-ground carbon in Mg in each ecosystem type[33].

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[32] cleanenergyregulator.gov.au/ERF
[33] 1 Mg = 1×10^6 grammes = 1,000 kg = 1 tonne

Soil organic carbon pool

Organic carbon density (in Mg/ha) in the top 30 cm of soil was derived from Viscarra Rossel et al. (2014a, 2014b). Viscarra Rossel et al. applied bootstrapping, piecewise regression and geostatistical modelling to several soil datasets captured in 2010 to derive estimates of soil organic carbon at approximately 90-metre resolution. Similar to the above- and below-ground carbon pool estimates, these densities were combined with the polygon-derived areal extent of each ecosystem type to derive the total stock of organic carbon in the top 30 cm of soil (in Mg) for each ecosystem type in the Mitchell.

Carbon sequestration

Details of carbon sequestration from Savanna Fire Management projects[34] within the Mitchell catchment were obtained from the quantities of Australian Carbon Credit Units (ACCUs) sourced through the Australian Government's ERF mechanism[35], using carbon crediting methodologies approved by the Clean Energy Regulator (CER)[36]. One ACCU corresponds to one tonne of CO_2-equivalent removed from the atmosphere, or one tonne of CO_2 release avoided[37]. Multiplying by the ratio 44/12 converts tonnes of carbon to tonnes of CO_2-equivalent (and thus converts tonnes of carbon stored to ACCUs) (Frydenberg, 2018; p.45). Data on the locations of Savanna Fire Management ERF projects that generated ACCUs from the Mitchell were obtained from the CER's interactive map[38]. Together with polygon-derived ecosystem type extents, this allowed the total number of ACCUs generated by ERF Savanna Fire Management projects within each ecosystem type to be quantified. Where a Savanna Fire Management project spanned multiple ecosystem types, ACCUs from the project were allocated proportional to the areas of overlap.

7.7.2 Soil and sediment retention services

Whilst the human population density across most of the Mitchell catchment is extremely low, the substantial number of cattle, relative to the cattle-carrying capacity of the catchment's ecosystems, have initiated soil erosion in multiple locations (Brooks et al. 2009, 2008; J. Shellberg, Brooks, & Spencer, 2010). Since the soil and sediment retention ecosystem service does not usually produce a marketed output, no direct measures of service supply are available. In these circumstances model-derived predictions of ecosystem service supply are typically used to produce estimates for inclusion in biophysical supply and use tables. The soil retention module in the InVEST modelling suite (Sharp et al. 2020) developed by the Natural Capital Project at Stanford University[39] has often been used for this purpose (e.g., Hamel et al. 2015; Udayakumara and Gunawardena, 2021; Wenger et al. 2020).

The challenges inherent in applying the biophysical modelling approach that sits behind InVEST's soil retention module to estimate soil *erosion* (i.e., the 'loss' of the soil and sediment *retention* service) in the Mitchell catchment were explored in NESP Project 4.6. Full

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[34] cleanenergyregulator.gov.au/Infohub/case-studies/Pages/erf-case-studies/Emission-Reduction-Fund-case-studies.aspx - Savanna-fire-management
[35] Data sourced from cleanenergyregulator.gov.au/ERF at close of business 24/01/2021.
[36] cleanenergyregulator.gov.au/ERF/Choosing-a-project-type
[37] cleanenergyregulator.gov.au/OSR/ANREU/types-of-emissions-units/australian-carbon-credit-units
[38] Interactive map data on source locations of projects generating ACCUs obtained from cleanenergyregulator.gov.au/maps/Pages/erf-projects/index.html
[39] naturalcapitalproject.stanford.edu/software/invest

details are provided in the associated publication[40] (McMahon et al. 2022) and its accompanying Biorxiv pre-print (see following page). The soil erosion estimates from McMahon et al. (2022) under pre-clearing and post-clearing land uses for the catchment as a whole (without allocation to separate ecosystem types) are listed in the biophysical supply and use tables. The estimated increase in soil erosion between pre-clearing and post-clearing timeframes (c. 1750 to 2015) [estimated to be 3,983 ktonnes/year] is indicative of the ***reduction*** in the soil and sediment retention service supplied by ecosystems in the Mitchell catchment over that period. A further consequence of this estimated increase in soil erosion is an increase in the quantity of sediment transported to the lower catchment, delta and coastal zone of the Gulf of Carpentaria. This increased sediment flux will likely impact on the function of receiving ecosystems; these impacts are not quantified or explored further in this Project, although other projects within the NESP Northern Australian Environmental Resources Hub have addressed related issues (e.g., nespnorthern.edu.au/projects/nesp/links-gulf-rivers-coastal-productivity).

[40] https://doi.org/10.1016/j.jenvman.2022.115102

Biorxiv link

biorxiv.org/content/10.1101/2021.08.06.455476v4

Pre-print title

Challenges in modelling the sediment retention ecosystem service for an ecosystem account, with examples from the Mitchell catchment

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Abstract

If soil resources and the benefits derived from water quality are to be maintained, the on- and off-site effects of soil erosion must be adequately represented and communicated to decision-makers so that appropriate management responses can be identified. The System of Environmental-Economic Accounting–Ecosystem Accounting (SEEA EA), is one approach to quantify both the contributions that ecosystems make to the economy, and the impacts of economic activity on ecosystems. However, due to the difficulty of obtaining empirical data on ecosystem service flows, in many cases such quantification is informed by ecosystem service models. Previous research on the Mitchell catchment, Queensland Australia allowed us to explore the implications of using a model of hillslope erosion and sediment delivery in isolation (as represented in one of the most frequently used ecosystem service models – InVEST) by comparing such estimates against multiple lines of local empirical data, and a more comprehensive representation of locally important erosion and deposition processes through a sediment budget model. Estimates of the magnitude of hillslope erosion modelled using an approach similar to InVEST and the calibrated sediment budget differed by an order of magnitude. If an uncalibrated InVEST-type model was used to inform the relative distribution of erosion magnitude, findings suggest the incorrect erosion process would be identified as the dominant contributor to suspended sediment loads. However, the sediment budget model could only be calibrated using data on sediment sources and sinks that had been collected in the catchment through a sustained research effort. A comparable level of research investment may not be available to inform ecosystem service assessments elsewhere. The results summarised here for the Mitchell catchment demonstrate that practitioners must exercise caution when using estimates of the sediment retention ecosystem service flow which have not been calibrated and validated against locally collected empirical data.

7.8 Estimating biophysical service supply of cultural services

7.8.1 Recreation-related services

Feral pig hunting, recreational fishing and wildlife collection for home consumption were listed in Table 16 as biomass provisioning services supplied by ecosystems in the Mitchell catchment for use by households. In addition to contributing to supply of these biomass harvesting services, ecosystems in the Mitchell also contribute, to varying degrees, to more general recreation-related cultural service flows. The SEEA EA (White cover version) notes that recreation-related services necessarily involve some form of interaction between people and ecosystems, but that in many instances human-made capital is channelled through business to facilitate or support those interactions. The SEEA EA (White cover version) cites nature tour guides, kayak hire companies or suppliers of entry permits for natural sites as examples of businesses that *facilitate access to recreational interactions with ecosystems*, whereas accommodation providers, restaurants, and fuel suppliers are cited as examples of businesses that *supply goods or services that support recreational interactions with ecosystems* (United Nations et al. 2021; paragraphs 7.49 and 7.50, p.169). These businesses are considered to utilise recreation-related services from ecosystems as inputs to a joint production process that supplies access, goods and services to recreational visitors – with the ecosystems' input being particularly evident and significant for the first category of businesses: the 'access facilitators'. The major challenge for Ecosystem Accounting is how to isolate the ecosystem inputs to these business operations within the SNA benefits (i.e., the sale : purchase transactions) that have already been recorded in standard national accounts.

The SEEA EA (White cover version) recommends that the number of visits (i.e., number of visitor days) should be reported in supply and use tables as the biophysical metric of the supply and use of recreation-related cultural services within Ecosystem Accounts, (United Nations et al. 2021; paragraph 7.52 and Table 7.6, p.170). Use of recreation-related cultural services should be assigned to households and supply should be assigned to the ecosystem type within which the recreational visit occurs (United Nations et al. 2021; paragraph 7.52 and Table 7.6, p.170). Supply will, however, be easier to assign for some types of recreation than others (e.g., guided barramundi fishing charters compared with wilderness camping).

Recreational visitor numbers in the Mitchell catchment are difficult to determine. The Mitchell catchment sits within the Tropical North Queensland tourism region. This region stretches 1,000km along the Reef coast from Cardwell in the south to the tip of the Torres Strait Islands in the north, and 850km from the Reef coast in the east to the Northern Territory border in the west. Tourism Research Australia (TRA) reported 10,351,000 visitor nights (international and domestic visitors combined) in the Topical North Queensland tourism region in the 12 months prior to 30th June 2019 (tra.gov.au). However, it is likely that the majority of these visitor nights were spent along the Reef coastline and in the rainforests on the eastern side of the Dividing Range, although the Tablelands region around Mareeba and Dimbulah in the extreme east of the Mitchell catchment is also likely to host appreciable numbers of visitors (Stokes et al. 2017; p.30–33).

TRA conducts regular surveys of international and domestic visitors and provides summaries of findings, averaged over the preceding four years, at LGA resolution for those LGAs where respondent numbers are sufficient to allow adequately robust results to be estimated. Under the 2018 Australian Statistical Geography Standard (Volume 3, 2018)[41], four LGAs overlap the Mitchell catchment to an appreciable extent: Carpentaria Shire (20% of the LGA area falls in the Mitchell catchment), Cook Shire (11% in the Mitchell), Kowanyama Aboriginal Shire (91% in the Mitchell), and Mareeba (69% in the Mitchell). TRA visitor summaries are available, averaged across the four years preceding June 2019, for Carpentaria Shire, Cook Shire and Mareeba Shire[42]. Mareeba Shire obtains a higher proportion of its visitor nights from overseas visitors than do Cook Shire and Carpentaria Shire, and in all three LGAs

[41] abs.gov.au/statistics/standards/australian-statistical-geography-standard-asgs-edition-3/latest-release
[42] Respondent numbers for Kowanyama were insufficient to allow robust results to be produced.

average expenditure per night is higher for domestic visitors. Apportioning LGA overnight visits and expenditures proportionally to the area of the LGA in the Mitchell catchment produces totals of approximately 258,000 international and 308,00 domestic visitor nights in the Mitchell, and a corresponding total visitor expenditure of $46.1 million. This may be an overestimate, however, as although 69% of Mareeba Shire LGA lies in the Mitchell, most visitors to Mareeba Shire visitors are unlikely to venture west from the Tablelands into the main body of the Mitchell catchment.

To assign these visits – and the accompanying expenditures – to ecosystem types as the supplier of ecosystem-sourced inputs to recreation-related ecosystem services, the locations of fee-paying caravan and camping sites across the Mitchell catchment were obtained from the online search tool 'WikiCamps Australia' (wikicamps.com.au) (Figure 29). In total, 34 fee-paying sites were identified (28 camping sites and 6 caravan sites) and their locations were mapped to their associated ecosystem type at polygon resolution. For caravan and camping sites in combination, 47% of sites were located in the Non-remnant Broad Vegetation Group, 32% in T4.2 – *pyric tussock savanna*, 12% in T4.3 – *hummock savanna*, 6% in TF1.2 – *subtropical-temperate forested wetlands*, and 2% in T4.4 – *temperate woodlands*. Visitor overnight stays are allocated to these ecosystem types in these proportions in the biophysical supply and use tables in the Mitchell Ecosystem Accounts, with expenditures apportioned equivalently in the monetary supply and use tables.

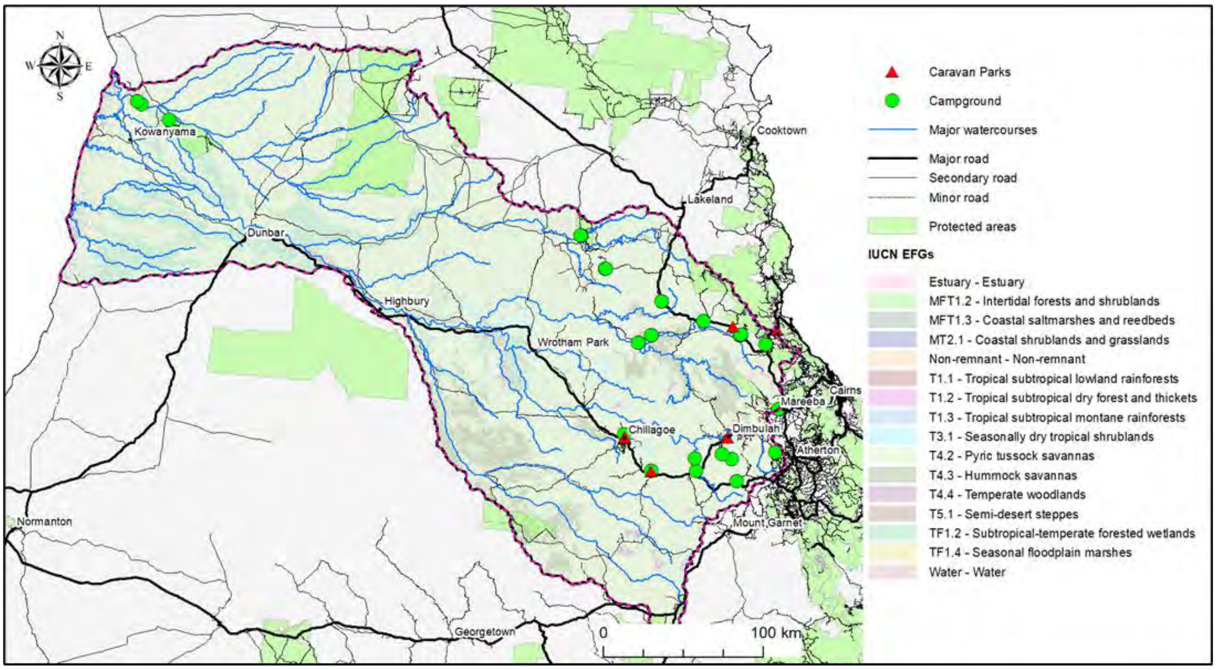

Figure 29. Locations of fee-paying caravan and camping sites in the Mitchell catchment, overlaid on ecosystem types. Main towns and roads shown.

7.8.2 Cultural ecosystem services received and contributed by Indigenous communities

The Millennium Ecosystem Assessment (MEA) defines cultural ecosystem services as:

> '… the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences' (MEA, 2005; Box 2.1, p.40).

The MEA assesses six main categories of cultural ecosystem services: cultural diversity and identity; cultural landscapes and heritage values; spiritual services; inspiration (such as for arts and folklore); aesthetics; and recreation and tourism. The MEA also acknowledged the important related concept of *services to ecosystems* (introduced by Comberti et al. (2015), and discussed in the following paragraphs):

> 'At the same time, humankind has influenced and shaped its environment to enhance the availability of certain valued services.' (MEA, 2005; p.120)

but subsequent development of a *unidirectional* ecosystem services paradigm '*from* ecosystems *to* people' failed to retain this important *reciprocity*. Drawing on the heritage of the MEA, the March 2021 specification of SEEA EA defines cultural ecosystem services as:

> 'Cultural services are the experiential and intangible services related to the perceived or actual qualities of ecosystems whose existence and functioning contributes to a range of cultural benefits.' (United Nations Statistics Division, 2021; Section 6.51, p.126).

and further notes that:

> 'The label 'cultural services' is a pragmatic choice and reflects its longstanding use in the ecosystem services measurement community. It is not implied that culture itself is a service, rather it is a summary label intended to capture the variety of ways in which people connect to, and identify with, nature and the variety of motivations for these connections.' (United Nations Statistics Division, 2021; Footnote 58, p.126)

The reference list of ecosystem services in the March 2021 specification of SEEA EA (United Nations Statistics Division, 2021; Table 6.3, p.126–129) distinguishes five categories of cultural ecosystem services:

- recreation-related services
- visual amenity services
- education, scientific and research services
- spiritual, artistic and symbolic services
- other cultural services.

The accompanying descriptions for each category are somewhat broader and more flexible than the naming initially suggests. For example, recreation-related services can include 'experiential interactions with the environment'; education, scientific and research services can include 'biophysical characteristics and qualities of ecosystems, that enable people to use the environment through intellectual interactions with the environment'; spiritual, artistic and symbolic services can include 'services [that] may underpin people's cultural identity'; and 'other cultural services' remains a broad catch-all.

As noted in Section 7.2, SEEA EA adopts an anthropocentric, instrumental value paradigm. It is therefore not surprising that fundamental misalignments occur between SEEA EA conceptualisations of anthropogenic interactions with ecosystems and those of Indigenous Traditional Owners. SEEA EA's conceptualisation is fundamentally 'linear' and 'transactional' (as exemplified in the *linear* sequence of contributions *from* ecosystems delivering benefits *to* society (Figure 1), and Ecosystem Accounts seek to represent *transactional use* values (United Nations et al. 2021; Section 6.3.4 and particularly paragraph 6.72, p.137)). In contrast, Indigenous Traditional Owners' conceptualisation is 'reciprocal' and 'relational', with *reciprocal* responsibilities between custodians and Country; custodians have responsibilities to care for Country in order for Country to continue to contribute benefits to custodians (e.g., Jackson et al. 2014; Strang, 2000). The values arising from those reciprocal interactions are grounded in the fundamental *relationship* between custodians and Country (e.g., Chan et al. 2016). Earlier conceptualisations of ecosystem services in the Millennium Ecosystem Assessment recognised that reciprocal relationships can be important components of societal interactions with ecosystems (e.g., MEA, 2005; Box 2.1, p.120). Drawing on this heritage, the SEEA EA (White cover version) recognises that there are situations in which relational values are relevant and important; however, the SEEA EA White cover version clearly states that *non-use value* and *relational value* fall *outside* the remit of SEEA Ecosystem Accounts (United Nations et al. 2021; Section 6.3.4 and particularly paragraph 6.72, p.137)).

In Project 4.6 we do not attempt to comprehensively describe how Indigenous peoples of the Mitchell River catchment measure and value the contributions that ecosystem services supply to their society. Given our understanding of the ways in which Indigenous peoples conceptualise socio-ecological relations (S. Jackson & Palmer, 2015), we acknowledge that Indigenous perspectives cannot be incorporated into SEEA EA in any straightforward way. The ontological category of 'nature' cannot be taken for granted as a source of ecological stocks and flows. Instead, Indigenous peoples *co-produce* with Country and the ecosystem services flow from that *relation*. The concept of *co-production* recognises that responsibilities under customary law require that custodians care for Country appropriately in order for Country to continue to provide ecosystem services. Comberti *et al.* (2015) consider that the standard linear conceptualisation of ecosystem services is flawed in framing ecosystems services as *'a one-way flow of benefits from ecosystems to humans'* (Comberti *et al.* 2015; p.247). They argue that local and Indigenous communities often play an important role in providing 'Services to Ecosystems' (S2E), which they define as:

> 'Actions humans have taken in the past and currently that modify ecosystems to enhance the quality or quantity of the services they provide, whilst maintaining the general health of the cognised[43] ecosystem over time' (Comberti *et al.* 2015; p.247)

Comberti *et al.* argue that the conventional linear, unidirectional ecosystem services paradigm should be extended to become an *'ecosystem services and services-to-ecosystems loop of reciprocity'* (Comberti *et al.* 2015; p.257).

The SEEA EA (White cover version) Table 6.3 description of 'services [that] may underpin people's cultural identity' can accommodate the value (in the sense of an increase in

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43 The term 'cognised' here recognises that local or Indigenous understandings of what constitutes the 'ecosystem' that is being managed may differ from those held by western science.

wellbeing) that Traditional Owners derive from fulfilling their custodial responsibilities by caring for Country in ways that align with the 'services to ecosystems' concept in Comberti et al's loop of reciprocity (Comberti et al. 2015; p.257). Survey-based research by Larson et al. (2019) with the Ewamian people (Traditional Owners of land in the Gilbert and upper Mitchell catchments) found that 'Knowing that Country is being looked after' (Larson et al. 2019; p.89) can also be an important source of wellbeing for Indigenous people – beyond just those custodians who are involved on-ground in caring for Country. Thus, 'knowing that Country is being cared for' could be viewed as a cultural ecosystem service in its own right. The wellbeing that Indigenous people derive from knowing that Country is being cared for can be further enhanced by knowing that Country will *continue* to be cared for into the future. This is evidenced by the importance that Traditional Owners place on passing on knowledge of how to care for Country to younger generations. These conceptualisations of cultural ecosystem service value facilitated by Comberti et al's 'loop of reciprocity' can all be accommodated within SEEA EA's descriptions of cultural ecosystem services, either via the link to cultural identity, or by introducing *caring for Country*, *knowing that Country is being cared for*, and *knowing that Country will continue to be cared for*, as cultural ecosystem services in their own right in the 'other cultural services' category. This latter approach is preferred as it makes 'services to ecosystems' explicit as a value delivery mechanism within SEEA EA, and thus evidences the importance of the 'loop of reciprocity' to Traditional Owners.

Environmental-economic accounts necessarily promote standardisation and equivalence, where complex socio-ecological processes are made amenable to assessment that can be used and compared across wider landscapes, different policy actors, and multiple stakeholders (McElwee, 2017). In the Mitchell River catchment there are many groups (Indigenous and non-Indigenous) with interests in the environment and varied forms of attachment and connection. Concepts and metrics common to the methodologies of ecosystem accounting are likely to be unfamiliar to some if not many and may well be contested. The 'tools' that ecologists and economists use to enumerate the living and life-giving processes of the Mitchell River catchment delineate a 'natural' world that does not align with Indigenous ways of knowing Country. The selection of which ecosystem services to enumerate, the objectification of phenomena (into 'catch', for example) and the choice of spatial and temporal scales will generate forms of knowledge that are contestable (McElwee, 2017) and therefore warrant more focused attention and discussion with Indigenous people of the study locality. Our team did not discuss which new things (the indicators, statistics, maps, or economic values reported here) should be created to stand in for the actual ecosystem processes, functions, and products that are considered beneficial or valuable. The Traditional Owners, Elders and Rangers of the Kowanyama community did, however, kindly share Indigenous knowledge of the following topics:

- interactions with Country that support supply of provisioning, regulating and cultural ecosystem services, (where these terms are used in their SEEA EA sense)
- how interactions with Country for multiple purposes are adversely affected by declining ecosystem condition – particularly by invasive weeds and feral animals
- cataloguing of on-Country activities as a potential starting point for developing SEEA EA-compliant valuations of some cultural ecosystem services (as conceptualised by SEEA EA) – recognising that any valuations that might be produced would only provide a very limited, partial representation of the full value that Traditional Owners and the Kowanyama community derive from the associated cultural and custodianship practices.

Notwithstanding these fundamental conceptual misalignments, and operating within the limitations of its field work budget and Covid-19 access restrictions, Project 4.6 investigated how Indigenous Traditional Owners' activities and interactions with Country could potentially be represented in SEEA Ecosystem Accounts for the Mitchell catchment – adopting SEEA EAs standard categorisation of provisioning, regulating and cultural ecosystem services. Drawing on several decades of residence in and interaction with the Kowanyama community, operating with the support of Kowanyama Aboriginal Land and Natural Resource Management Office, Abm Elgoring Ambung RNTBC, and Kowanyama Aboriginal Council, and collecting data in accordance with Griffith University Human Research Ethics Approval No. 2019/850, Project 4.6 Research Associate Viv Sinnamon's research reported that the Indigenous Traditional Owners in Kowanyama both benefit from a range of provisioning and cultural ecosystem services and facilitate supply of a range of regulating and cultural ecosystem services. Viv's research describes how Traditional Owners' ability to benefit from and supply provisioning, regulating and cultural ecosystem services is being compromised by the declining condition of ecosystems in the lower Mitchell catchment and delta. The primary pressures reported as causing these problems are invasive weeds and feral animals.

8. Ecosystem services in monetary terms

8.1 Valuing ecosystems' contributions to benefits

To ensure consistency with SNA globally, ecosystem accounting is based on the concept of *exchange value* (Obst et al. 2016; United Nations, 2017; United Nations, European Union, Food and Agriculture Organization of the United Nations, Organisation for Economic Co-operation and Development, et al. 2014). In deriving the ecosystem service monetary supply and use tables in Ecosystem Accounts, the biophysical quantities in the biophysical supply and use tables are multiplied by their respective *market or exchange prices* to produce *exchange values*. For a transacted good included in national accounts, the exchange value represents the 'SNA benefit' i.e., the total revenue that a producer receives for supplying a given quantity of the good (or service). The exchange value encompasses the producer's surplus and the cost of production (Figure 30) but does not include the consumers' surplus component.

Applying this exchange-based valuation approach to goods or services that are not already represented in the SNA, (i.e., when attempting to value a non-SNA benefit) requires finding an appropriate exchange price that can be applied to an '*imputed exchange of (or transaction in) ecosystem services between a given ecosystem asset (e.g., a forest) and an economic unit (e.g., a forestry company) or individual (e.g., a visitor to a forest)*' (United Nations, 2017, p.98). The price estimated for the imputed exchange could be termed an *exchange-equivalent price*, which then enables the value of the imputed transaction to be termed the *exchange-equivalent value*.

Expressing ecosystem services in monetary terms using SNA-aligned valuation approaches allows incorporation of some ecosystem services that are not normally freely exchanged in markets into SNA-format, i.e., this introduces 'non-SNA benefits'. Potential augmentation of SNA with the non-SNA benefits supplied by ecosystems would provide a more complete picture of the market and exchange-equivalent value of the basket of final goods and services produced in a country or region over a given time period. Viewed through the lens of SNA, Ecosystem Accounts thus report the 'exchange-equivalent' value of the basket of ecosystem services that are actually utilised by people i.e., at the point at which the ecosystem service flows enter either the utility function of individuals (e.g., directly as non-SNA benefits, such as an improvement in air quality) or the production function of an economic agent (e.g., as ecosystems' inputs to the production of SNA benefits, such as a fish catch by a commercial fishing vessel) (Schröter et al. 2014).

It is important to note, however, that ecosystem accounts do ***not*** measure welfare gains or 'gains from trade', as given by the combined consumers' and producer's surpluses (Area A + Area B in Figure 30). Instead, in common with the SNA, they report the transacted exchange value ($P_{market} \times Q_{sold}$ = Area B + Area C) for marketed goods and services (i.e., SNA benefits), or exchange-equivalent value for non-marketed goods and services (i.e., non-SNA benefits).

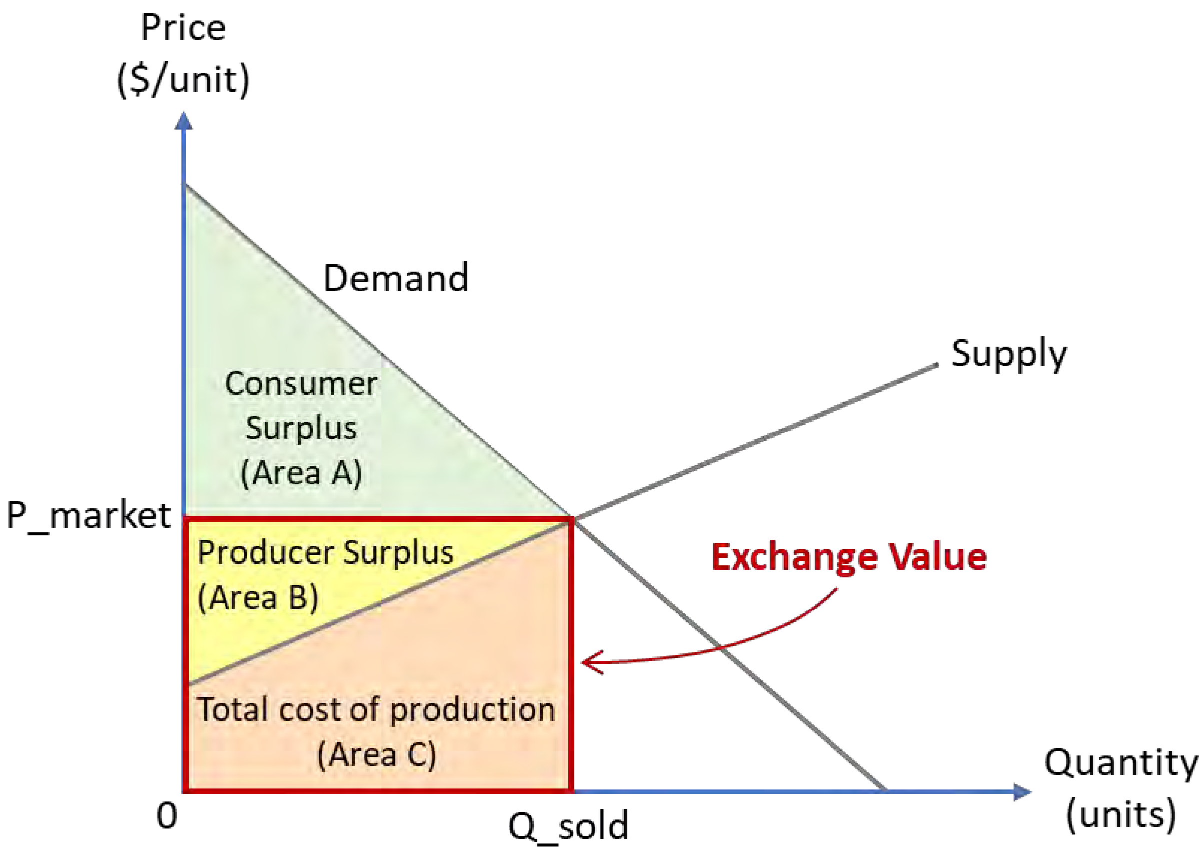

Figure 30. Consumer surplus, producer surplus, cost of production and exchange value.

Valuation techniques that are considered appropriate for estimating relevant exchange values or exchange-equivalent values for ecosystems' inputs to joint production processes that generate SNA benefits and ecosystems' contributions to the supply of non-SNA benefits are described in the SEEA EA (White cover version) (United Nations et al. 2021; Section D, p.176–222). Some example applications of methods for estimating exchange value or exchange-equivalent value in published literature that are generally compliant with the exchange value principles of SEEA EA are shown in Table 18.

Table 18. Summary of valuation techniques that are consistent with SEEA EA exchange value (Obst et al. 2016; United Nations, 2017) and example applications in published literature.

Valuation technique	Description	Example applications in published literature
Unit Resource rent or Residual value method	Also called residual imputation or net rents (Brouwer et al. 2009). Represents the return on natural assets used in production (European Commission et al. 2009). The value of the ecosystem service is the residual that remains after deducting labour costs, user costs of produced assets and costs of intermediate inputs from the exchange price received for the market benefit.	Provisioning services (timber, oil palm, rattan, paddy rice) (Sumarga, Hein, Edens, & Suwarno, 2015) Provisioning service (harvested fish, abstracted water) (Lai et al. 2018) Provisioning services (crop and fodder production) (Remme et al. 2015) Cultural service (nature recreation) (Sumarga et al. 2015) Cultural service (nature tourism) (Remme et al. 2015)
Production/cost/profit functions	Econometric estimation of marketed goods (e.g., barramundi) as a function of conventional economic inputs and ecosystem services. This estimation technique is to derive the (marginal) contribution of ecosystem services to the marketed output.	Cultural service via a household production function (different forms of recreation) (Martin, Mongruel, & Levrel, 2018)
Replacement cost	A cost-based approach for valuing services associated with ecosystem processes such as air filtration or nutrient assimilation. The value of replacing the specific ecosystem service is estimated using the costs of the next best alternative consisting of produced assets and associated inputs.	Provisioning service (groundwater extraction for drinking water production) (Remme et al. 2015)` Regulating service (in-stream nitrogen retention) (La Notte et al. 2017)
Hedonic pricing	The exchange-equivalent price of an ecosystem service is obtained by splitting the values of marketed assets (e.g., houses) into the values associated with specific characteristics. This enables valuations for ecosystem services (e.g., green space for recreation) to be separated from the characteristics of the house (e.g., number of bedrooms) and its neighbourhood (e.g., crime rate).	-

Table 18 (continued).

Valuation technique	Description	Example applications in published literature
Avoided damage cost/Marginal social damage costs (Tol, 2018, 2019)	The value of the ecosystem service is estimated using the cost of damages that would be incurred if the ecosystem services were to be reduced or lost. Mainly applicable to valuing carbon sequestration and storage using the social cost of carbon. The social cost of carbon is determined using the marginal social damage cost function for carbon emissions which reports the increase in damage costs imposed on society by each successive tonne of carbon emission and the consequent temperature increase through climate change. If one tonne of carbon is sequestered, the marginal social damage cost of carbon curve can be used to determine the saving in damage costs.	Regulating services (carbon sequestration) (Sumarga *et al.* 2015) Regulating services (carbon sequestration, air quality regulation) (Remme *et al.* 2015;)
Marginal exchange value from revealed demand functions	Exchange prices are estimated using available demand functions. The actual quantity consumed is substituted into the demand function to obtain an exchange-equivalent price for supply of the good or service concerned.	-
Averting behaviour	The value of the ecosystem service is estimated based on individual's willingness to pay for improved or avoid (typically) ill health or willingness to pay to avoid reduction in the service.	Cultural service (orangutan as flagship conservation species) (Sumarga et al. 2015)
Payment for ecosystem services	Exchange values for ecosystem services (typically regulating services) are estimated via the payments made to landholders to undertake remediation actions to improve delivery of ecosystem services from their land	-

The layout of the monetary supply and use tables in Ecosystem Accounts mirrors that of the biophysical supply and use tables, but outcomes are expressed in monetary units using appropriate methods for determining exchange value. Exchange values for ecosystems' contributions to supply of SNA benefits and non-SNA benefits in the Mitchell catchment were determined as described in the following subsections.

8.2 Valuation approaches for provisioning services

Following SEEA EA (White cover version) (United Nations et al. 2021; Section 9.3 generally, and paragraph 9.36, p.195 specifically), and consistent with the approach recommended in SEEA-CF (United Nations et al. 2014b; Section 5.4.5), the residual value method is used to estimate the exchange value of provisioning services that represent ecosystems' contributions to joint production processes that generate SNA benefits. Examples include fish catches as an input to the commercial fishing industry, pasture grazing fodder as an input to livestock production, and soil nutrients, soil water and trace mineral inputs to the production of horticultural crops. The residual value method (Figure 31) subtracts the cost of all *other* inputs to the joint production process that generates the SNA benefit[44]; what remains – 'the residual' – is then regarded as the 'rent to the resource'. This 'residual' represents the maximum amount that the production business would be prepared to pay for the input(s) it received (for free) from the ecosystem(s).

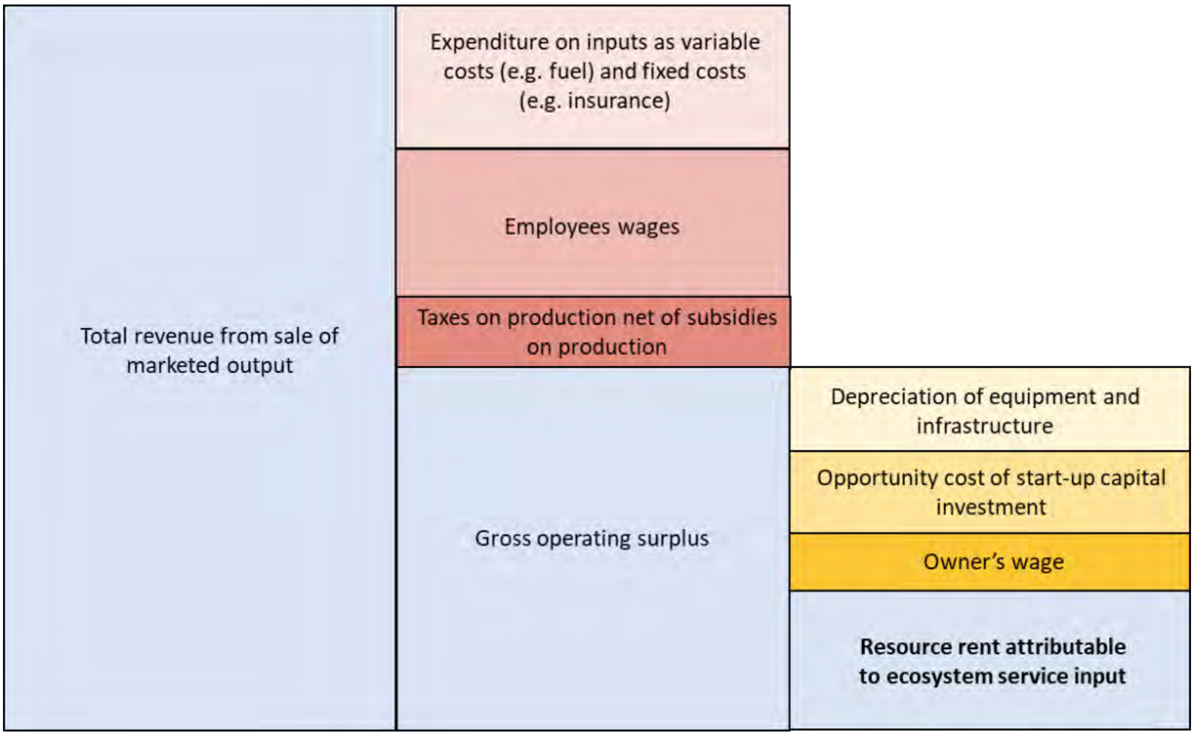

Figure 31. The residual value method for calculating the value of provisioning ecosystem services as inputs to a joint production process.

Referring back to the fishing business illustrated in Figure 25, the resource rent from a commercial fish catch would be calculated as shown in Figure 31, drawing on the resource rent calculation described in the SEEA EA (White cover version) (United Nations et al. 2021; Section 9.3 generally, and paragraph 9.36, p.196) and SEEA-CF (United Nations et al. 2014b; Table 5.5, p.153). Figure 31 shows that the following elements are *subtracted* from the revenue received from the sale of the marketed output to arrive at resource rent as the

[44] The SNA benefit generated is the revenue obtained from the sale of output from the joint production process.

exchange-equivalent value attributed to the ecosystem service input(s) to the joint production process:

- Expenditures on inputs and services purchased from other sectors of the production economy (e.g., diesel, fishing nets, ice for freezing the catch, fertiliser, agrochemicals, harvesting and transport, insurance services, accountancy services etc.) – termed *intermediate consumption* in SEEA EA (White cover version) (United Nations et al. 2021; Section 9.3 generally, and paragraph 9.36, p.196), and in SEEA-CF (United Nations et al. 2014b; Table 5.5, p.153). Some of these inputs will vary year to year with production output (e.g., diesel, harvesting and transport costs), others will be relatively fixed (e.g., insurance services, accountancy services). These *variable costs* and *fixed costs* are both included in the business's *intermediate consumption*.
- Wages paid to workers – termed *compensation of employees* in SEEA EA (White cover version) (United Nations et al. 2021; Section 9.3 generally, and paragraph 9.36, p.196) and in SEEA-CF (United Nations et al. 2014b; Table 5.5, p.153).
- Any *taxes* levied specifically on the joint production process, after first *adding* any specific *subsidies* applied to that process (as might be the case for some forms of agricultural production).

The net revenue remaining to this point is termed *gross operating surplus* in SEEA EA and SEEA-CF. In an agricultural setting, this would typically be termed *gross margin* (e.g., Bowen et al. 2019; Figure 1, p.21). The following items are then *subtracted* from gross operating surplus (or gross margin) to arrive at resource rent:

- Owner's wage ([*remuneration for*] *labour of self-employed persons* in SEEA EA (United Nations et al. 2021; paragraph 9.36, p.196)).
- The cost (in $) that the business incurs (during the year concerned) as a result of the capital investments it was required to make to setup production – termed the *user cost of produced assets* in SEEA-CF (United Nations et al. 2014b; Table 5.5, p.153). SEEA-CF explains that the *user cost of produced assets* comprises two components:
    - The *depreciation* (in $) of the business's capital assets during the year concerned
    - the [required] *return to produced assets* (i.e., the return (in $) that the business would expect on its start-up capital investment).

These two components of the *user cost of produced assets* are calculated as follows:

- *Depreciation*: In spreadsheets that are commonly used to calculate net returns to farming businesses, the depreciation of capital assets during the course of a year is typically calculated via the *straight line* method (e.g., publications.qld.gov.au/dataset/agbiz-tools-plants-fruits-and-nuts). In straight line depreciation, the value of an asset reduces from its original purchase price by a fixed amount each year such that it reaches a given *scrap value* (either $0 – if deprecation is complete – or a fixed percentage of the asset's original value, e.g., 30% of original asset value) at the end of a defined *lifetime*. Mean lifetimes for different classes of capital asset (e.g., vehicles, buildings, orchards) are specified in the Australian System of National Accounts (Australian Bureau of Statistics, 2021; Chapter 14). Asset lifetimes of 5, 10, 15 or 20 years are commonly used for vehicles and machinery, and asset lifetimes of 30 years or more for major infrastructure (e.g., buildings, irrigation channels and weirs) in farm budgeting spreadsheets. The total decline in the value (in $) of all the business's capital assets from one year to the next comprises the *depreciation* component of the user cost of produced assets.

- Drawing on SEEA-CF (United Nations et al. 2014b; paragraphs 5.141–5.144, p.156) here we set the [required] *return to produced assets* for the business to equal the 1.75% coupon yield rate of FY2020/2021 Australian Government 11-year bonds[45]. Thus, in each year, the business's [required] return (in $) on the total capital investment it made to setup production is calculated as 1.75% of that total capital investment.

The *user cost of produced assets* in each year comprises the sum of depreciation and the required (1.75%) return to the business's start-up capital investment.

What remains (i.e., 'the residual') when all of these items have been subtracted from the gross revenue received for the produced output is the *resource rent* that provides an exchange-equivalent valuation for the ecosystem's contribution to the joint production process, i.e., an *exchange-equivalent valuation for the provisioning ecosystem service input*.

This residual value method is used to produce exchange-equivalent valuations for biomass provisioning services from ecosystems in the Mitchell catchment as explained in the following subsections.

8.2.1 Crop provisioning services

The SEEA EA (White cover version) recommends that valuation of provisioning ecosystem services that contribute to production of agricultural crops should focus on identifying *ecosystems' contribution* to the exchange value of the agricultural crop outputs that are traded in markets (United Nations et al. 2021; paragraph 9.68, p.201). As explained in the preceding section, the value of ecosystems' contributions to the exchange value of agricultural crop outputs can be estimated by the residual value method, derived from crop market revenues net of the full suite of relevant costs for inputs (including labour) and the user cost of produced assets (Figure 31) (United Nations et al. 2021; paragraph 9.36, p.195).

Detailed data on all relevant costs (i.e., startup capital costs as well as annual variable and fixed operating costs) were not available for all crops produced on irrigated land in the Mitchell catchment; however, the requisite revenues and costs were available via whole-of-farm business models for four of the catchment's main irrigated crops (by area and value): avocado, banana, mango and sugarcane. Cost data for avocado, banana and sugarcane were obtained via whole-of-farm business models from Queensland DAF (farmtable.com.au/build/agbiz-tools-plants-field-crops-pastures and publications.qld.gov.au/dataset/agbiz-tools-plants-fruits-and-nuts) as follows: avocado (Avocado (Shepard) – whole of farm model – Mareeba-Dimbulah Irrigation Area), banana (Cavendish Banana – whole of farm model – Mareeba-Dimbulah Irrigation Area), and sugarcane (Sugarcane – whole of farm model – Atherton Tablelands). Full cost data for a

[45] We use the 1.75% coupon yield rate of the 11-year Australian Federal Government Bond GSBU32 issued 13th April 2021- term 21st November 2032 to be indicative of the required return to produced assets because capital assets in agriculture are typically assigned long lifetimes (www.australiangovernmentbonds.gov.au/bond-types/exchange-traded-treasury-bonds/list-etbs)

Northern Territory-based 3,000 tree mango production operation were obtained from Ngo and Owen (2002).

Representative per hectare revenues for the four crops were obtained from the 2019 Tablelands Agricultural Profile (Mareeba Chamber of Commerce, 2020) for avocado, banana and mango, and – for sugarcane – from the average of the Tablelands Agricultural Profiles for 2010 and 2015 (State of Queensland Department of Agriculture and Fisheries, 2010, 2015). All revenues were escalated to FY2020/21 AUD$ using the Reserve Bank of Australia (RBA) inflation calculator (rba.gov.au/calculator).

Knowing the relevant revenues and costs (all escalated to FY2020/21 AUD$), the residual value attributed to supply of crop provisioning services in irrigated avocado, banana, mango and sugarcane production in the Mareeba-Dimbulah irrigation area are determined as follows.

- Annual gross revenue is calculated as the product of annualised average yield per hectare from the relevant whole-of-farm model[46] and the relevant crop price from the 2019 Tablelands Agricultural Profile (Mareeba Chamber of Commerce, 2020) escalated to FY2020/21 using the RBA inflation calculator (rba.gov.au/calculator). Annualised average yields reflect the time taken for trees to reach full cropping potential (for avocado and mango) and differing yields from the initial 'plant' crop and subsequent 'ratoon' crops (for banana and sugarcane).
- Annualised average variable costs and annual fixed costs (including owner's wage) are derived from the relevant whole-of-farm model, with individual cost elements escalated from the year in which the whole-of-farm business model was compiled to FY2020/21 via appropriate ABARES (December 2021) inflation indices for the cost of agricultural inputs (Australian Bureau of Agricultural and Resource Economics and Sciences, 2021). The ABARES input cost categories used for escalation are: fuel, fertiliser, chemicals, marketing, vehicle and machinery maintenance, electricity, water, and labour.
- Capital input requirements for the farm businesses are derived from the relevant whole-of-farm model, with capital cost elements escalated from the year in which the whole-of-farm business model was compiled to FY2020/21 via the ABS Producer Output Price Indexes for Australia (December 2021): Construction Industries – Non-residential building construction Queensland (for capital expenditure on buildings); and Manufacturing Industries – Agricultural machinery and equipment manufacturing (for capital expenditure on machinery and equipment) (Australian Bureau of Statistics, 2021b) . The annual user cost of capital for the business is derived from these capital input requirements as explained in Section 8.2.
- For each business, the annual residual value is calculated as annual gross revenue minus annualised average variable cost, annual fixed cost (including owner's wage) and the annual user cost of fixed capital (all escalated appropriately to FY2020/21 AUD$). Annual residual value is expressed per hectare.
- Total residual value for crop provisioning services to irrigated avocado, banana, mango and sugarcane production in the Mitchell is obtained by multiplying per

[46] publications.qld.gov.au/dataset/agbiz-tools-plants-fruits-and-nuts for avocado, banana and sugarcane; Ngo and Owen (2002) for mango.

hectare residual value by the number of hectares of each crop grown in the Mitchell catchment as derived from 2018–2021 remote sensing imagery by the Applied Agricultural Remote Sensing Centre, University of New England (2022).

For reasons that will be explained in Section 8.2.5 on water supply services for irrigation, it is likely that a proportion of the residual value attributed here to crop provisioning services may well be attributable to ecosystems' contributions to the supply of water services. To avoid double counting, however, the valuation is reported in the Supply and Use Tables only once, under 'crop provisioning services', with a footnote on this point added under water supply services.

8.2.2 Grazed biomass provisioning services

The residual value method was applied to produce an exchange-equivalent valuation of the grazed biomass provisioning service from ecosystems in the Mitchell by using the estimates of cattle numbers (as AEs) per ecosystem type within the Grazing Native Vegetation QLUMP land use class as described in Section 7.6.3 and reported in the biophysical supply and use tables in the Mitchell's Ecosystem Accounts.

Drawing on farm business data collected by Rolfe et al. (2016), Ash et al. (2018) developed business models for representative beef enterprises in different parts of the Mitchell catchment to evaluate the potential performance and profitability of innovations such as the introduction of irrigated forage to boost herd performance. As part of their evaluation, Ash et al. necessarily reported the baseline financial performance of their representative beef enterprises operating under standard extensive grazing purely on native pastures (Ash et al. 2018; Table 2-3, p.15). Ash et al. report representative gross margins (per AE) for grazing enterprises at Highbury and Dunbar ($211 and $193 per AE, respectively (Ash et al. 2018; Table 2-3, p.15)). From these gross margins, Ash et al. then calculate representative net profits before interest and tax ($/AE) by subtracting owner's labour cost and the fixed costs of operating the farm business (*including* interest paid on debt, but *not* including the user cost of produced assets (as depreciation and the required return to capital) to arrive at an average net profit (before interest and tax) of $125/AE (escalated to $128.75/AE in FY20/21 AUD$ using the Reserve Bank of Australia's inflation calculator (rba.gov.au/calculator/financialYearDecimal.html). This net profit of $128.75/AE is used as the exchange-equivalent price for the 'residual' to produce an exchange-equivalent valuation for the grazing biomass provisioning service supplied to grazing enterprises by ecosystems in the Mitchell. As explained in Section 7.6.3, the value of the biomass provisioning service supplied per ecosystem type is allocated in direct proportion to the AE numbers attributed to each ecosystem type in the grazing native vegetation QLUMP land use within the Mitchell catchment.

Using this method, the total annual exchange-equivalent value of grazing biomass provisioning services supplied by ecosystems in the Mitchell is estimated to be $17.6 million/year, of which $14.1 million/year is supplied by *pyric tussock savanna*, $1.6 million/year by *subtropical/temperate forested wetlands*, and $1.2 million/year by *hummock savannas*.

This approach over-estimates the residual value somewhat because Ash et al's net profit before interest and tax does not account for the user cost of produced assets (i.e., depreciation of capital assets and the required rate of return to capital). Lacking details on the capital stock holding for representative grazing enterprises in the Mitchell, this final component in the residual value calculation cannot be implemented. The valuation produced here for grazed biomass provisioning services should therefore be regarded as indicative only.

8.2.3 Wild fish provisioning services

An indicative valuation for wild fish provisioning services supplied to the commercial barramundi fishery that operates in the Mitchell estuary and its immediate coastal zone is estimated by assuming that the residual value is 20% of the gross margin per tonne harvested. Gross margin data are obtained from McMahon et al. (2021; Table 2, p.22).

8.2.4 Wild animals, plants and other biomass provisioning services

A valuation could not be produced for biomass provisioning services of wild animals, plants and other biomass direct to households and visitors in the Mitchell catchment because catchment-wide data were not available from which biophysical service supply could be estimated. If biophysical service supply estimates available per species had been available, then the replacement cost approach of Jackson et al. (2014b) could potentially have been used to produce a valuation. It would, however, likely be very challenging to obtain catchment-wide, per species estimates of wild biomass harvests – so this remains an opportunity for further research.

8.2.5 Water supply services for irrigation and households

A recent review of Sunwater irrigation water pricing by the Queensland Competition Authority found that irrigation water pricing in the Mareeba-Dimbulah Irrigation Area was insufficient to cover the operating, maintenance and capital renewal costs of the water supply scheme (Queensland Competition Authority, 2020). Consequently, ecosystems' contributions to water supply services for irrigated agriculture *cannot* be determined by applying the residual value method to the water services supply sector because there is no 'residual', i.e., irrigation water pricing is not high enough to generate a surplus to the water service supplier (here, Sunwater) once operation, maintenance and capital renewal costs have been accounted for. In this context, the value of ecosystems' contributions to irrigation water supply is passed on directly from the water service supplier to farmers[47] and thus appears as part of the surplus that accrues to farmers when the value of crop provisioning services is calculated via the residual method (as detailed in Section 8.2.1).

The SEEA EA (White cover version) suggest that the *productivity change method* could potentially be used in these circumstances to derive an exchange-equivalent price for ecosystems' contributions to irrigation water supply (United Nations et al. 2021; paragraphs 9.38 and 9.39, p.198). The productivity change method uses the marginal net revenue product of irrigation water (i.e., how much additional gross margin the farmer would obtain from applying an extra ML per hectare of irrigation water to their crop) as the basis for determining the value of the irrigation water supply service. Location-specific crop-water

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[47] In addition, farmers receive a subsidy on their production to the extent that the price they pay for water does not fully recover the operating, maintenance and capital renewal costs incurred in supplying water to the farm gate. (Here we assume that the capital cost of the Scheme's original water supply infrastructure assets has previously been written off by the Government.)

production functions (additional yield per additional ML) and location- and time-specific crop water requirements (how much additional water does a specific crop in a specific location require in a particular growing season to attain the farmer's desired crop yield) would be required to apply the productivity change method successfully. This information was not available to the authors for tree cropping in the Mareeba-Dimbulah Irrigation Area, hence the productivity change method could not be used to produce a valuation of water supply services for irrigation.

Similar data and information challenges prevent an exchange-equivalent value being estimated via the residual value method for ecosystems' contributions to household water supply via offtakes from the Mareeba-Dimbulah Scheme's irrigation channel (for the town of Dimbulah and neighbouring Mutchilba), or for the groundwater-derived water services supplied to residential properties in Chillagoe and Kowanyama. The authors have been unable to determine whether the fixed per-property annual water charges for these locations (Dimbulah: $543/residential property/year; Chillagoe: $543/residential property/year (Mareeba Shire Council, 2020); Kowanyama: $1,240/residential property/year (Kowanyama Aboriginal Shire Council, n.d.)) are sufficient to fully recover the operating, maintenance, capital renewal and capital recovery costs of the relevant water supply systems. Hence, valuations are not provided in the Monetary Supply and Use Tables for household water supply services.

8.3 Valuation approaches for regulating services

8.3.1 Global climate regulation services

SEEA EA (White cover version) recognises carbon sequestration and carbon storage as contributions to the global climate regulation service (United Nations et al. 2021; Section 6.4.3). Section 7.7.1 described how carbon storage and carbon sequestration were quantified in biophysical terms for ecosystem types in the Mitchell catchment. SEEA EA (White cover version) provides general guidance on methods that can be used to obtain exchange values, or exchange-equivalent values, for different categories of ecosystem services (United Nations et al. 2021; Section 9.4). For carbon sequestration and carbon storage, anthropogenic benefits accrue from the reduction in climate change-induced damages that would follow from a reduction in greenhouse gas concentrations in the atmosphere, either from direct sequestration or from avoided release of stored carbon. SEEA EA (White cover version) presents a hierarchy of exchange-based or exchange-equivalent valuation methods, in preference order, with the highest preference accorded to valuation using a price derived from directly observable monetary exchanges at 'economically-significant prices' in mature markets (United Nations et al. 2021; paragraph 9.23, p.193; footnote 94, p.195).

With regard to carbon sequestration, Australia's Clean Energy Regulator operates a national carbon market in Australian Carbon Credit Units (ACCUs) on behalf of the Emissions Reductions Fund, with 1 ACCU equating to 1 tonne of CO_2-e sequestered (cleanenergyregulator.gov.au/Infohub/Markets/Pages/About-Carbon-Markets.aspx). Businesses or other entities wishing to offset their carbon emissions can purchase ACCUs from the national carbon market for this purpose. After several years of relatively low demand for carbon offsets and correspondingly low ACCU pricing (~ $15/tonne), demand for ACCUs as carbon offsets increased rapidly during the latter half of 2021, with the ACCU price reaching $30/tonne during October and subsequently rising to more than $50/tonne by the end of December (accus.com.au). This suggests that the Australian national carbon market in ACCUs can now be considered 'mature' and the corresponding prices 'economically significant'. Hence, here we use a representative October 2021 ACCU price of $30/tonne of CO_2-e sequestered to value the *carbon sequestration* element of the global climate regulation service provided by savanna fire burn management in ecosystem types in the Mitchell catchment. Using this approach, the estimated annual value of carbon sequestration services via marketed ACCUs from savanna fireburn management in the Mitchell's ecosystems is $3.5 million in total, of which $3.2 million comes from ACCUs generated from savanna fireburn mangagement in *pyric tussock savanna*.

The SEEA EA (White cover version) also indicates that, in appropriate circumstances, exchange-equivalent prices for supply of ecosystem services can be derived by estimating the additional expenditures or reduced incomes that would result for economic units (businesses, households and governments) if an ecosystem service were no longer to be provided (United Nations et al. 2021; Section 9.3.6). The *avoided damage cost* approach is one such method for determining exchange-equivalent prices and is noted as being suitable for valuing global climate regulation services (United Nations et al. 2021; Paragraph 9.52, p.198). Here we apply this approach to value the *carbon storage* component of the global climate regulation service provided by ecosystem types in the Mitchell.

Section 7.7.1 described how the quantity of carbon stored in above- and below-ground biomass and the organic carbon stored in the top 30 cm of soils in the Mitchell's ecosystems was quantified in biophysical terms. If the Mitchell's ecosystems had not supplied this carbon storage, CO_2-e concentrations in the atmosphere would be higher and additional damage costs would be incurred in the Australian, and world, economies because of consequent increases in temperature (Burke, Hsiang, & Miguel, 2015). The total present value of the estimated additional damage cost incurred by a national economy, or the global economy in aggregate, from the temperature change caused by an additional tonne of CO_2e in the atmosphere can be calculated under appropriate assumptions (see, for example, Burke et al. 2015 and Ricke et al. 2018). The resulting additional damage cost per additional tonne of CO_2-e released – or, equivalently, the additional damage cost that would result from $\frac{12}{44} = 0.273$ fewer tonnes of carbon storage (Frydenberg, 2018; p.45) – is termed the 'social cost of carbon' (Ricke et al. 2018). The social cost of carbon can be estimated at global or country-specific level, with Ricke et al. (2018) providing a comprehensive set of relatively up to date estimates, under a wide range of well justified scenarios.

Here, consistent with the avoided damage cost method described in SEEA EA (White cover version) (United Nations et al. 2021; Paragraph 9.52, p.198) and prior practice (e.g., Mikhailova et al. (2019)) we use Ricke et al's social cost of carbon for Australia (under their reference scenario[48]) of $5.14/tonne CO_2-e (equivalent to $5.24/tonne CO_2-e in AUD$ 2020) to value (in $) the carbon stored in above- and below-ground biomass and the organic

[48] Ricke et al's (2018) reference scenario for estimating global and country-specific social costs of carbon comprises Shared Socioeconomic Pathway 2 and Representative Concentration Pathway 6.0, and Burke et al's (2015) 'short run' (i.e., not lagged) economic damage function, with growth-adjusted ('Ramsey') discounting with a pure rate of time preference of 2% per annum and an elasticity of marginal utility substitution of 1.5.

carbon stored in the top 30 cm of soils in the Mitchell's ecosystems. An annual valuation for the carbon storage service supplied by the Mitchell's ecosystems is produced as an annuity ($/year) derived from the total value of the carbon stored. Following the approach taken recently under UN SEEA's Natural Capital Valuation and Accounting Programme (NCAVES) (Government of India, 2021), and consistent with findings of the Interagency Working Group on the Social Cost of Greenhouse Gases (IWG) (National Academies of Sciences Engineering and Medicine, 2017; Chapter 6, p.168), we apply the standard annualisation formula (Boardman et al. 2001; p.144), assuming a social discount rate of 3% per annum[49] over an infinite timeframe. The corresponding annuity value ($/year) is thus 3% of the value of the total stock of carbon stored, where the stock value is determined using Ricke et al's social cost of carbon for Australia, escalated to 2020 AUD$.

Using this annualisation approach, the annual value of carbon storage services from ecosystems in the Mitchell is $502 million in total, of which $110 million arises from carbon stored in above- and below-ground biomass, and $391 million arises from organic carbon stored in the top 30 cm of the soil[50]. On a per hectare basis, the annuity value of carbon storage ranges from $162/ha for *tropical/subtropical montane rainforests* (of which $55/ha is from carbon stored in above- and below-ground biomass, and $107/ha is from organic carbon stored in the top 30 cm of soils), through $72/ha ($17/ha in biomass, $55/ha in soils) for *pyric tussock savannas* (the Catchment's largest ecosystem type by area), to $48/ha ($5/ha in biomass, $43/ha in soils) for *coastal saltmarshes and reedbeds*.

Different CO_2-e prices are used to produce exchange values for carbon sequestration (the ACCU market price of $30/tonne of CO_2-e) and carbon storage (the social cost of carbon for Australia at $5.24/tonne of avoided CO_2-e derived damage cost). This reflects the different property right contexts that surround carbon sequestration and release of stored carbon. The market price for ACCUs generated from carbon sequestration derives from businesses willingness to pay for offsets to cover their carbon liabilities. In this context, businesses acknowledge that they do not hold the property right to release carbon emissions to the atmosphere. Consequently, they must incur costs to offset their emissions. This property right position could have emerged due to mandatory (e.g., carbon emissions regulations) or voluntary (e.g., scrutiny from investors) drivers. In contrast, there is currently no carbon emission liability associated with release of stored carbon (e.g., through woodland clearing that considerably reduces stored above- and below-ground carbon (Heather Keith et al. 2021)). Businesses that release stored carbon are not required to purchase ACCUs to offset their consequent CO_2 emissions; in effect, the property right to release stored carbon sits with carbon emitter. This implicitly grants the emitter the right to impose the climate-related damage costs on society. Hence, in this context, CO_2 emissions from release of stored carbon are valued using the social cost of carbon for Australia, which is an estimate of the damage costs incurred by society. (Noting that greenhouse gas emissions are a uniformly mixing global pollutant, it could be argued that release of stored carbon should be valued using the *global* social cost of carbon, rather than the Australian social cost of carbon. This would produce a much higher valuation for carbon storage services as Ricke et al's global

[49] A 3% per annum discount rate is the central discount rate used by Ricke et al. in their suite of scenarios to evaluate the social cost of carbon Ricke et al. (2018).
[50] Valuations do not sum correctly due to rounding.

social cost of carbon (escalated to AUD$ 2020) is $425.63/tonne of avoided CO_2-e; more than 80 times the Australian value.)

8.4 Valuation approaches for cultural services

8.4.1 Recreation-related services

In the absence of data on estimated visitation demand functions and direct expenditure on travel costs, SEEA EA (White cover version) recommends that the exchange value of recreation-related services can be calculated by summing relevant consumption expenditures (United Nations et al. 2021; para. 9.48, p.197). This is the approach adopted in Project 4.6, using the visitor numbers reported in the biophysical supply and use tables (Section 7.8.1), together with per-night LGA-specific expenditures for domestic and overseas visitors provided by Tourism Research Australia for the 2019 season for the Carpentaria, Cook and Mareeba Shire LGAs (tra.gov.au/Regional/local-government-area-profiles), escalated to FY20/21 AUD$ using the RBA inflation calculator (rba.gov.au/calculator).

8.4.2 Valuation approaches for Indigenous cultural ecosystem services within SEEA EA

Although it has long been recognised that cultural ecosystem services make important contributions to human wellbeing, cultural ecosystem services have featured much less frequently in economic valuation assessments than provisioning and regulating services (recreation-related cultural ecosystem services are the exception) (see, for example, de Groot et al. 2012). This likely reflects the difficulty in quantifying their value in monetary terms (cultural ecosystem service values supplied through recreation and tourism are again the exception).

This challenge is more acute when attempting to place a value on the cultural services that Indigenous people derive from ecosystems and their custodianship of Country. Stoeckl et al. (2018) show that the economics toolkit for valuing simple individual goods is much more developed than the toolkit for valuing complex social goods. They argue that this has led to a focus on valuation of simple individual goods as the basis for informing policymaking. An unintended consequence may be that the institutions and behaviours required to produce complex, socially constructed ecosystem service values are at risk of being ‘crowded out’ through lack of policy awareness (Stoeckl et al. 2018). Sangha, Russell-Smith and Costanza (2019) relate similar concerns and advocate that decision-making around sustainable development practices must recognise and understand that nature underpins the wellbeing of Indigenous and local communities in ways that go far beyond merely livelihood opportunities.

Hirons, Comberti and Dunford (2016) provide a comprehensive review of methods that have been used to value cultural ecosystem services. They document 24 different methods spanning quantitative and qualitative, monetary and non-monetary, spatial and non-spatial, deliberative and non-deliberative dimensions, that have been implemented with or without stakeholder involvement. This breadth of assessment methods reflects the plurality of values associated with cultural ecosystem services (Hirons, Comberti and Dunford, 2016; Section 4, p.556–558), and further emphasises the challenge inherent in attempting to produce monetary valuations of cultural ecosystem services that comply with the exchange value-based paradigm of SEEA EA. This challenge is particularly acute for cultural ecosystem services supplied to and by Indigenous communities.

The importance of concepts akin to cultural ecosystem services and Comberti et al's *loop of reciprocity*, and *relational value* more generally, in supporting and enabling the cultural, spiritual and socio-economic livelihoods and wellbeing of Indigenous communities in northern Australia has been well documented in the literature (e.g., Altman and Jackson, 2014; Barber and Jackson, 2017; Russell-Smith et al. 2013; Sangha et al. 2019; Scheepers and Jackson, 2012). The particular challenges in producing appropriate valuations of the suite of ecosystem services – including cultural ecosystem services and 'services to ecosystems' that arise from custodianship of Country – supplied by and delivered on Indigenous-managed land in northern Australia have been highlighted recently by Sangha et al. (2017).

In the Mitchell River catchment, Traditional Owners undertake a range of activities to manage land and water, fulfil custodial responsibilities under customary law and sustain their way of life (Marcus Barber, 2015; Scheepers & Jackson, 2012a; Strang, 1999). In this light, SEEA Ecosystem Accounts can potentially play a role in drawing the importance of Traditional Ownership of Country to the attention of decision-makers by including (albeit partial and incomplete) estimates of the value generated by custodianship-related activities on Country.

Research from other parts of the world on *relational values* is challenging the uni-directional, individualistic and instrumental/utilitarian premise of the ecosystem services framework (Chan et al. 2016; Comberti et al. 2015; Díaz et al. 2018; Kenter, 2016). With respect to Indigenous Australia, the labour and practices of Indigenous communities have been framed as the means by which some Australian Indigenous communities *co-produce* ecosystem services (S. Jackson & Palmer, 2015). The concept of co-production recognises that responsibilities under customary law require that custodians care for Country appropriately in order for Country to continue to care for custodian communities by supplying ecosystem services. The *bi-directional* nature of the *relationship* between custodians and Country forms the basis for a reconceptualising of the interdependencies between custodians, Country and ecosystem service flows. To the best of the authors' knowledge, this bi-directional perspective has not yet been applied to a local/regional Indigenous context in which evidence exists both for such co-production and for the significance of catchment ecosystem service flows and interdependencies.

The original intention of Project 4.6, before Covid-19 travel restrictions emerged as a constraint, was to seek to quantify and, if possible, estimate a value metric for the contributions that Traditional Owners of the Kowanyama area make by maintaining the condition of ecosystems and thus ensuring sustainable delivery of ecosystem service flows. We intended to do this by obtaining an understanding of how the Kowanyama community, households and family groups chose to allocate their scarce community and household resources (e.g., personnel, time, effort, knowledge, vehicles and equipment) to produce beneficial provisioning, regulating and cultural ecosystem service outcomes through custodianship of Country via on-Country activities. Beneficial outcomes from on-Country activities could include, for example, harvesting of barramundi, turtles, and magpie goose eggs; enhanced individual wellbeing through time spent on-Country; management actions to maintain or improve the condition of Country – for example, managing feral animals and weeds, savanna burning to reduce fuel load for late-season wildfires; and enhancing sustainable management into the future by passing on knowledge about caring for Country to the next generation.

These different outcomes are valued by the local community because they are recognised as making positive contributions to individual and societal wellbeing (Larson et al. 2019). In a SEEA EA framing, these contributions to wellbeing can be categorised as provisioning (e.g., resource harvesting), regulating (e.g., savanna fire burn), or cultural ecosystem services (e.g., time spent on Country, enhanced wellbeing because community know that Country is being cared for and that knowledge of how to care for Country is being passed on to the next generation), and as investments that enhance the long-term capacity of ecosystems to deliver ecosystem service flows (e.g., caring for Country; passing on of knowledge).

In this context, two approaches for producing SEEA EA compliant estimates that could potentially reflect *some portion of* the values arising from these interactions between custodians and Country were considered, as described in the following sub-sections.

The 'cost of inputs' approach

The Australian SNA recognises that 'social transfers in kind' deliver substantial value to households and individuals in society. Social transfers in kind are defined as follows:

> '… goods and services provided to individual households by general government units and non-profit institutions serving households. The goods and services may be produced by the government units and NPISHs or purchased by them from market providers. They are provided to households for free or at prices that are not economically significant[51].' (Australian Bureau of Statistics, 2021; paragraph 13.88, p.410)

Education and health services are typically regarded as this type of 'social transfer in kind' and would usually be classified as 'non-market outputs' in SNA (Australian Bureau of Statistics, 2021; paragraph 9.12, p.126). In these circumstances, market prices are unlikely to exist for the services delivered, so a valuation for the services provided is calculated in SNA by summing *'the costs of producing the outputs, comprising compensation of employees, the cost of purchased goods and services used in production (intermediate consumption), other taxes (less subsidies) on production and consumption of fixed capital'* (Australian Bureau of Statistics, 2021; paragraph 9.13, p.126) i.e., summing the 'cost of inputs' required to supply the service as an output.

This 'cost of inputs' approach that SNA uses to value 'caring for people', i.e., delivering health services, could also potentially be applied to 'caring for Country'. Were a 'cost of inputs' approach to be followed however, stark contrasts would immediately be apparent in the scale of the attributed value. Government expenditures on 'caring for people' comprise a very high wage bill for a large workforce (many of whom have extremely high levels of knowledge and expertise), very considerable expenditures on produced inputs (medicines, high technology equipment, vehicles, surgical implants etc.), and very substantial capital investments in built infrastructure (hospitals, operating rooms, clinics etc.). In contrast,

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[51] When prices are "not economically significant", the price of the good or service is sufficiently low that it does not affect demand for that good or service, i.e., in the context of 'social transfers in kind' the government heavily subsidies the cost of providing the goods or services concerned with the intention that they should be readily accessible to all households.

although Traditional Owners' caring for Country also relies on individuals with extremely high levels of knowledge and expertise, this is unlikely to be reflected in wage rates, and only very modest expenditures on produced inputs and built infrastructure are likely to be incurred. Consequently, an SNA and SEEA EA-compliant 'cost of inputs' approach for valuing Traditional Owners' caring for Country would grossly under-represent the value that Indigenous communities place on caring for Country, knowing that Country is being cared for, and passing on knowledge of how to care for Country to future generations. For these reasons, the 'cost of inputs' approach was not pursued in Project 4.6.

The 'opportunity cost of outputs' approach

An 'opportunity cost of outputs' approach could also potentially be used to provide a SEEA EA-compliant, estimate <u>*of part of the value*</u> that Traditional Owners derive from caring for Country, knowing that Country is being cared for, and passing on knowledge of how to care for Country to future generations. The basis for this approach is as follows.

An indication of how the Kowanyama community, families and households value the positive contributions that these cultural ecosystem services make to individual and societal wellbeing is the extent to which they *voluntarily* commit *scarce resources* (e.g., personnel, time, effort, knowledge, vehicles and equipment) to on-Country activities that care for Country and pass on knowledge of caring for Country to future generations. The underlying principle is that resources that are 'scarce' are valuable. 'Scarcity' applies when there is not enough of a resource to allow it to be used in all possible 'value generation pathways'. Consequently, decisions have to be made regarding to which 'value generation pathway(s)' the available amounts of resources should be committed. After acknowledging relevant constraints, these resource allocation decisions can be used to infer the *relative* value that families and communities place on *outputs* from the different 'value generation pathways'.

For example, previous analyses of active Indigenous hunters and land managers (Marcus Barber, 2015) suggest that this portion of the population is usually time poor; consequently, demand for these individuals' time exceeds supply and their time is therefore a scarce resource. Demand for other resources such as effort, knowledge, vehicles and equipment is also likely to exceed available supply, thus ensuring that these resources are also 'scarce' – and therefore valuable – in an economic sense. The way in which family groups and community choose to allocate these scare resources to different on-Country activities can tell us a lot about the *relative values* that families and community attach to the *outcomes* of those activities.

An initial intention in Project 4.6 was to explore, through workshop discussions with Traditional Owners and households in Kowanyama, how people chose to configure combinations of scarce household and community resources to deliver particular outcomes from time spent on Country. In an economic framing, this information could be used to define the *'bundles' of inputs* required to produce particular levels of different ecosystem service *outputs* by undertaking particular activities at specific locations. A dataset could then be assembled of the input resource bundles (e.g., personnel, time, effort, knowledge, vehicles and equipment etc.) required to produce particular levels of outputs (e.g., barramundi catch, magpie goose egg harvest, control of invasive weeds or feral animals, on-Country activities and ceremony). If a sufficiently large dataset could be assembled, distance-function approaches (after Vaughn Aiken, 2006) could be used within a household production framework, to parameterise the output tradeoffs that would follow from committing particular bundles of resource inputs to different on-Country activities. This would establish the opportunity cost (in terms of the foregone output of one on-Country activity e.g., the catch from barramundi fishing) that would follow from committing a particular bundle of scare resources (personnel, time, effort, knowledge, vehicles and equipment) to another on-Country activity (e.g., sharing on-Country traditional knowledge with emerging elders).

Previous TRaCK research with Kowanyama households established (quasi-) market valuations for some provisioning ecosystem service outputs from on-Country activity: harvested barramundi, turtles, goose eggs etc. (Jackson, Finn, & Scheepers, 2014). This enables an exchange value to be established for barramundi catch. It would also enable a SEEA EA-compliant exchange value to be placed on the barramundi catch *foregone* when a particular bundle of scarce resources is committed to *another* on-Country activity. In this way a SEEA EA-compliant exchange value could be determined for the activity to which that bundle of scarce resources had been committed.

Unfortunately, the intended Project 4.6 face-to-face workshops were not held in Kowanyama due to Covid-19 access restrictions. An online workshop was, however, conducted with members of Kowanyama Aboriginal Land and Natural Resource Management Office, Abm Elgoring Ambung RNTBC, and Kowanyama Aboriginal Council. These organisations provided support for Project 4.6 research associate Viv Sinnamon – a longstanding Kowanyama resident and collaborator – to collect data on on-Country resource harvesting activities, locations, and the bundle of resources required to harvest the relevant resources (e.g., barramundi, turtles, magpie goose eggs) (see FigureB1 and FigureB2). These data enabled resource harvesting patterns for particular species across ecosystem types to be established for the wet and dry seasons, and informed further data collection regarding the extent to which resource harvesting and value generation from other on-Country ecosystem services were impaired by weed infestations and feral animals. Data were collected in accordance with Griffith University Human Research Ethics Approval No. 2019/850.

As we were unable to conduct further face-to-face workshops and discussions with the Kowanyama community, we do not know whether an ‘opportunity cost of outputs’ valuation approach – and the *partial* representations of the value of on-Country activities that it would produce – would be meaningful and acceptable to Traditional Owners and the Kowamyama community. Lacking the necessary dataset, and without an endorsement of the appropriateness (or otherwise) of the proposed methodology from the Kowanyama community, we did not pursue this valuation approach further in Project 4.6.

9. Mitchell catchment: pilot ecosystem accounts

In accordance with SEEA EA practice, the Mitchell catchment, extended seven nautical miles into its coastal zone, is defined as the 'ecosystem accounting area', for which ecosystem accounts in Project 4.6 are compiled. The data from which the Pilot SEEA Ecosystem Accounts for the Mitchell are compiled are described in detail in the Project 4.6 Data Inventory document. The SEEA Ecosystem Accounts are presented in the Pilot SEEA Ecosystem Accounts document. This chapter provides a brief summary of the data that were used and refers the reader to the Pilot Ecosystem Accounts document to view the compiled accounts and the Data Inventory for additional data details as appropriate.

9.1 Ecosystem extent accounts

[Ecosystem Accounts Chapter 2 – particularly Tables 1–4 and Figures 7 & 8; Data Inventory Chapter 2]

9.1.1 Cross-walking of Broad Vegetation Groups of Queensland and IUCN Global Ecosystem Typology

[Ecosystem Accounts Sections 2.1 & 2.2; Data Inventory Chapters 1 and 2; particularly Sections 2.1 and 2.2.]

Cross-walking between Remnant Broad Vegetation Groups of Queensland (Version 4.0, 2017) (Neldner et al. 2019) and the IUCN Global Ecosystem Typology (IUCN GET) (D. A. Keith et al. 2020), in consultation with experts at the Queensland Herbarium, matched all Remnant BVG polygons in the Mitchell catchment (~31,000 polygons from 61 BVGs at 1:1 million scale) across to 13 IUCN GET Ecosystem Functional Groups (EFGs) (see Data Inventory Table 1 for a full list of the matching between Queensland Remnant BGVs and IUCN GET EFGs). The 13 EFGs do not cover areas that are categorised in the Queensland BVG GIS layer as 'estuary', 'non-remnant' and 'water'. Thus, the Mitchell catchment's Extent Account effectively comprises 16 *ecosystem types* (13 IUCN EFGs and 3 Qld BVG classes).

The extent of each ecosystem type (in ha) is reported in the Extent Account pre-clearing (~1750) and post-clearing (~2015). Ecosystem extents for ecosystem types in the Mitchell's Extent Account are derived from Qld BVG polygons mapped across to the relevant IUCN EFG (or retained as the estuary, non-remnant or water BVGs). The sum of the post-clearing (~2015) BVG *polygon-derived* areas for ecosystem types in the Mitchell catchment is 7,172,218 ha. Thus, the total extent reported in the Mitchell catchment Extent Account is 7,172,218 ha.

9.1.2 GIS 'edge effects' in calculating ecosystem extents

[Data Inventory Section 1.1]

The sum of post-clearing BVG *polygon* areas (7,172,218 ha), as reported in the Ecosystem Extent Account, exceeds the total extent for the Mitchell catchment calculated using GIS *raster* data (7,171,100 ha) due to GIS 'edge effects'. Edge effects prevent complete spatial alignment between raster-based and polygon-based datasets. This results in some post-clearing ecosystem type extents as reported in the Extent Account (derived from EFG matching of BVG *polygons*) being slightly larger than the extents of the same ecosystem types derived using *raster* datasets. These discrepancies give rise to a spatial error of approximately 0.0156% in total extent (1,118 ha in a total (polygon derived) area of 7,172,218 ha); this discrepancy is considered negligible.

Subsequent reporting of ecosystem condition variables for ecosystem types in the Mitchell is derived from GIS *raster* data. Hence, the areal extents for ecosystem types in the Mitchell Condition Account for the Mitchell sums to 7,171,100 ha, rather than the 7,172,218 ha shown in the Extent Account.

9.1.3 Supplementary ecosystem extents for waterbodies and rivers

[Ecosystem Accounts Section 2.3 – Tables 5 & 6, Figures 9 & 10; Data Inventory Section 2.4]

A Supplementary Extent Account for waterbodies and rivers is compiled as follows. Rivers are described by the area covered by water (in km^2) and by their linear features, reported as length in kilometres, for the most recent year (2020). Watercourse areas are split between estuarine (8%) and freshwater (92%). A significant proportion of freshwater watercourse areas are non-perennial as opposed to perennial. Similarly, perennial watercourse lines in the Mitchell catchment are much shorter in total length than non-perennial watercourse lines.

9.1.4 Land uses in the non-remnant Broad Vegetation Group of Queensland

[Ecosystem Accounts: Section2.4 , Table 7 and Figures 11–16; Data Inventory: Section 2.3, Tables 4 & 5, Figures 4 & 5]

As previously described, a proportion of Queensland's native vegetation was cleared between pre- and post-clearing periods, resulting in the BVG class 'non-remnant'. The non-remnant BVG can be further delineated using available land uses mapped under the Queensland Land Use Mapping Program (QLUMP). Most of the non-remnant area is situated in the upper catchment and includes a section of the Mareeba Dimbulah Water Supply Scheme (MDWSS). Land uses within the non-remnant BVG, as mapped by QLUMP, were matched across (cross-walked) with the IUCN Global Ecosystem Typology to produce another set of IUCN EFGs under the T7 *Intensive land-use* biome for the non-remnant BVG (Ecosystem Accounts Report: Section 2.4, Table 7 and Figures 11–16; Data Inventory: Section 2.3, Table 4, Figures 4 & 5). This matching exercise produced a QLUMP – IUCN EFG correspondence that covered 97% (89,029 ha) and 96% (87,978 ha) of the non-remnant BVG extent in 1999 and 2015, respectively.

9.1.5 Land uses by ecosystem type in Mitchell catchment

[Ecosystem Accounts Section 2.5 Tables 8 & 9, Figures 17 & 18; Data Inventory Section 2.3]

To provide supplementary information to the ecosystem extent accounts, QLUMP land uses were further tabulated by ecosystem types for the Mitchell catchment for the most recent year available, 2015 (Ecosystem Accounts Tables 8 & 9; Data Inventory Tables 4 &5).

Grazing native vegetation is the dominant land use (~81% of the total catchment land area) with much of the remainder of the catchment area allocated for *Conservation and Natural Environments (Managed resource protection* and *nature conservation)* (15%). In total, 80%, 9% and 7% of the *grazing native vegetation* areas are in *pyric tussock savannas* (~4.6 million ha), *subtropical-temperate forested wetlands* (~0.5 million ha) and *hummock savannas* (~ 0.4

million ha), respectively. *Managed resource protection* and *nature conservation* together constitute 15% (just over 1 million ha) of the Mitchell's catchment area. Irrigated agricultural land use, whilst only constituting a small proportion of the catchment area at 0.3% (22,211 ha), remains an important economic usage producing high value crops such as avocados, bananas, mangoes, sugarcane and irrigated pastures.

As the 'grazing on native vegetation' land use occupies most of the Mitchell catchment, supply of grazing fodder for cattle rearing from ecosystem assets in ecosystem types within this grazing on native vegetation land use is an important provisioning service flow within the catchment. Total pasture dry matter biomass (kg DM/ha) provides a (positive) indicator of the *capacity* of ecosystem assets to deliver grazed biomass provisioning (United Nations et al. 2021; Table 6.3, p.131); however, the same parameter could be regarded as a negative indicator of condition for remnant BVGs. Pasture grasses are considered weeds in natural environments due to their competitive nature towards native grass species. In addition, their high biomass fuels hot fires (as opposed to the cool fires favoured by native species for natural regeneration and regrowth). Hence, pasture biomass and growth can be regarded as a threatening process from an ecological health perspective.

In areas where pasture is grown i.e., areas designated as an intensive land-use system within the non-remnant BVG (the T7 *Intensive land-use* biome in IUCN GET), specifically T7.2 *Sown pastures and fields* and T7.5 *Derived semi-natural pastures and old fields*, 'total pasture dry matter biomass' is an agricultural product that flows into the economy. In this instance, the corresponding final ecosystem service comprises the natural inputs (e.g., nutrients, water) – termed 'crop provisioning services' in the SEEA EA White cover version (United Nations et al. 2021; Table 6.3, p.131) – that contribute to the quantity of biomass harvested from these designated intensive land use areas.

Spatial information on land uses together with information on spatial extent of the 16 ecosystem types (13 IUCN EFGS and BVGs of non-remnant, water and estuary) were used to guide selection of ecosystem services for subsequent inclusion in the ecosystem service supply and use accounts.

9.2 Ecosystem condition variable account

[Ecosystem Accounts Chapter 3 – particularly Tables 10–13, Figures 21–27; Data Inventory Chapter 3]

The SEEA Stage 1 Ecosystem Condition Variable Account for the Mitchell (Ecosystem Accounts Table 10) comprises condition metrics (rows) organised by SEEA EA Ecosystem Typology Class [Abiotic physical state; Abiotic chemical state; Biotic compositional state; Biotic structural state; Biotic functional state; Landscape level characteristics] (United Nations et al. 2021; Section 5.2.3 and Table 5.1, p.90), with columns indicating the ecosystem types. Condition metrics are presented generically across the different ecosystems and are broadly consistent with the examples of ecosystem condition variables for selected ecosystem types outlined in the SEEA EA (White cover version) (United Nations et al. 2021; Table 5.7, p.106–107).

Condition variables that are not considered relevant for particular ecosystem types are indicated as such in the Condition Account by shading relevant cells in grey. For example, spatial distribution of waterholes is listed in SEEA EA as a landscape condition metric for deserts and semi-desert ecosystems, but not for other terrestrial ecosystem types. A second example given in SEEA EA (White cover version) (United Nations et al. 2021; Table 5.7, p.106–107) is the percentage of burnt area being a physical state variable for shrublands and shrubby woodlands, but not for tropical-subtropical forests, shrublands and shrubby woodlands, and savannas and grasslands.

Given that a wide variety of condition metrics have already been collected for the Mitchell catchment, it would be impractical to present subsets of condition variables that are specific for each separate ecosystem type. It was considered more appropriate to present the full set of variables generically across all ecosystem types in the Stage 1 (Variables) Ecosystem Condition Account for the Mitchell (Ecosystem Accounts Table 10).

The Stage 1 (Variables) Condition Account for the Mitchell Catchment (Ecosystem Accounts Table 10) features the variables listed in Table 19.

Table 19. Variables included in the Stage 1 (Variables) Ecosystem Condition Account for the Mitchell catchment.

Condition Variable		Ecosystem Account	Data Inventory
Stage 1 Condition Account		Table 10	
Abiotic physical characteristic			
	Waterbodies		Section 2.4
	Gully erosion	Figure 21	Section 3.1.2
Abiotic chemical characteristic			
	Biomass carbon		Sections 3.2.1.1 & 3.2.1.2
	Soil carbon		Section 3.2.1.3
	Coastal blue carbon		Section 3.2.1.4
Biotic compositional characteristic			
	Habitat for iconic fauna	Table 11, Figure 22	Section 3.3.1
	Species richness		Section 3.3.2
	Pest animal presence	Table 13, Figure 27	Section 3.3.3
	Weed presence	Table 12, Figure 26	Section 3.3.3
Biotic structural characteristic			
	Pasture biomass		Section 3.4.4
	Tree cover	Figure 24	Section 3.4.2
	Vegetation height		Section 3.4.3
	Woody vegetation cover	Figure 23	Section 3.4.1
Biotic functional characteristic			
	Pasture growth		Section 3.5.2
	Fire intensity	Figure 25	Section 3.5.1.3
	Fire pressure		Section 3.5.1.2
	Fire frequency	Table 17, Table 18, Figures 35 & 36	Section 3.5.1.1
Landscape level characteristic			
	Area burnt (fire scars)		Section 3.6.1
	Fragmentation	Table 18, Figure 37	Section 3.6.2

Without additional information on reference levels for each variable and additional knowledge to provide an agreed normative interpretation of the values of the condition variables, it was not possible to progress from a Stage 1 (Variables) to a Stage 2 (Indicators) Ecosystem Condition Account. Some of the condition variables such as iconic fauna species habitat extent, IUCN species richness, invasive species presence, fire intensity and fragmentation do provide some indication of the current condition of ecosystem assets particularly when those data are available over multiple years. For example, the pre-clearing period may imply absence of invasive species, high intensity fires and fragmentation[52]. Nevertheless, compiling condition variables systematically in the present study provides a starting point of comparison against similar ecosystem accounting work in the future.

9.3 Supplementary information

[Ecosystem Accounts Chapter 4; Data Inventory Chapter 4]

Data on Aquatic Conservation Assessment (ACA) values (Department of Environment and Science, 2018), also known as AquaBAMM 'aquatic scores', protected areas, and rainfall were compiled as Supporting Information for the Condition Account.

9.3.1 Aquatic Conservation Assessment scores

[Ecosystem Accounts Tables 14 & 15, Figures 28–33; Data Inventory Section 4.1.1]

AquaBAMM ACA scores were compiled for all freshwater riverine and non-riverine wetlands in the Mitchell catchment. Aquatic scores are classified into five categories: very high, high, medium, low and very low, and are available for both watercourse lines (in km) and water course areas (in km^2). Watercourse lines are further divided into major and minor by perenniality. Similarly, watercourse areas are divided into freshwater and estuarine, with a further subdivision into perennial or non-perennial.

9.3.2 Protected areas

[Ecosystem Accounts Table 16; Data Inventory Section 4.1.2]

The extent and types of protected areas in the Mitchell catchment were collated, based on Queensland wide data collected from 2003 to 2021 accessed via the Queensland Spatial Data Catalogue (Data Inventory Section 4.1.2). National Park covers a total area of 128,984 ha spanning six terrestrial ecosystem types (T1.1, T1.2, T1.3, T3.1, T4.2 and T4.3), two ecosystem types within the freshwater-terrestrial realm (TF1.2 and TF1.3) and a small area of the non-remnant BVG. Approximately 364,785 ha of the Mitchell catchment are allocated as protected area under National Park – Cape York Aboriginal Land. The extents of State Forest and Forest Reserve are much lower, covering 18 ha and 5,847 ha, respectively.

Protected areas allocated under Essential Habitat span all ecosystem types in the Mitchell catchment. Important Bird Areas, as a proportion of ecosystem type extent, are highest in

[52] We respectfully acknowledge that 'pre-clearing' (i.e., in approximately the year 1750), the land and water ecosystems in the Mitchell catchment were actively managed as socialised landscapes by the ancestors of today's Traditional Owners in fulfilment of their custodial responsibilities, and that this condition can be considered a "stable socio-ecological state" that could provide an appropriate 'reference' condition (United Nations et al. 2021; Annex 5.2, paragraph A5.1 and Table A5.8, p.115).

intertidal forests and shrublands (MFT1.2), *coastal saltmarshes and reedbeds* (MFT1.3), *coastal shrublands and grasslands* (MT2.1) and *estuary*, recognising these ecosystems as important habitats for many bird species. Significant proportions of *tropical-subtropical montane rainforests* (T1.3) are designated as National Park (75%), Essential Habitat (85%) and Important Bird Area (84%).

9.3.3 Rainfall

[Ecosystem Accounts Figure 34; Data Inventory Section 4.1.3]

Mean annual rainfall for the Mitchell catchment over the period 1880 to 2020 was collated and mapped using gridded meteorological data accessed via LongPaddock longpaddock.qld.gov.au/silo/gridded-data (Project 4.6 Data Inventory Section 4.1.3). Mean annual rainfall is highest (>300 mm per year) in areas adjacent to the Gulf of Carpentaria and generally declines further inland, rising to >300 mm per year again in the rainforests of the Dividing Range on the northern side of the catchment's eastern boundary.

9.4 Pressures on ecosystem condition

[Ecosystem Accounts Chapter 5; Data Inventory Chapter 5]

Data on environmental pressures were compiled to provide an alternative or indirect assessment of ecosystem condition in the Mitchell River catchment (European Commission, 2016; p.28). Data on the environmental pressures listed in Table 20 were compiled for this purpose.

Table 20. Environmental pressures included in the Environmental Pressures account for the Mitchell catchment

Environmental Pressure	Ecosystem Account	Data Inventory
Fire regimes	Tables 17 & 18, Figures 35 & 36	Sections 3.5.1.1, 3.5.1.2, 3.5.1.3 & 3.6.1
Fragmentation	Table 18, Figure 37	
Ground cover disturbance	Table 19, Figure 38	Section 5.1.2
Land clearing	Tables 20 & 21	Section 5.1.3
Pest animal and weed presence	Tables 12 & 13, Figures 26 & 27	Section 3.3.3
River disturbance	Table 22, Figure 39	Section 5.1.6

9.4.1 Fire regimes

[Ecosystem Accounts Tables 10,17 & 18, Figures 35 & 36; Data Inventory Sections 3.5.1.1, 3.5.1.2, 3.5.1.3 & 3.1.6]

Fire frequency can potentially be used both as a condition variable and as an environmental pressure. Fire pressure variables (percentage area of ecosystem type burnt within guideline frequencies; percentage area of ecosystem type burnt more frequently than recommended; percentage area of ecosystem type burnt less frequently than recommended), are derived by comparing spatially specific data on the number of burns over a 20-year period (2000 through to 2019) from NASA's North Australian Moderate Resolution Imaging Spectroradiometer (MODIS) fire frequency mapping (see Data Inventory) with the Queensland Government's Regional Ecosystem Fire Guidelines (Queensland Herbarium, 2021b). Maps are plotted showing the three fire pressure variables (Ecosystem Accounts: Figures 35 & 36; Data Inventory Figures70, 71, 76 – 79 & 82 - 84). A fire pressure indicator is constructed directly from the percentage of each ecosystem type that is burnt within the recommended frequency guidelines (ranging from 11% (for *Tropical-subtropical dry forests and thickets*) to 98% (for *Temperate woodlands*)), reported in Table 18 in the Ecosystem Accounts.

9.4.2 Fragmentation

[Ecosystem Accounts Tables 10 & 18, Figure 37; Data Inventory Section 3.6.2]

As was the case for fire frequency, fragmentation can potentially be regarded both as a landscape characteristic condition variable and as an environmental pressure. Fragmentation within ecosystem types in the Mitchell catchment was assessed with the FRAGSTATS v4.2 spatial analysis tool (McGarigal & Marks, 1995). Fragstats v4.2 was run on 25 m × 25 m raster data, pre-clearing and post-clearing, for each ecosystem type. Mean patch size for each ecosystem type was reported, pre-clearing and post clearing (Data Inventory Table 35.). The ratio of post-clearing patch size to pre-clearing patch size is calculated and used as an indicator of fragmentation pressure (Ecosystem Accounts Tables 10 & 18).

As an example, spatial plots are shown for the *pyric tussock savanna* ecosystem type, highlighting that fragmentation impacts are largely limited to those areas that have been cleared for agriculture (Ecosystem Accounts Figure 37; Data Inventory Figure 90).

9.4.3 Ground cover disturbance

[Ecosystem Accounts Table 19, Figure 38; Data Inventory Section 5.1.2]

We regard ground cover disturbance as a proxy for grazing pressure in rangeland ecosystem types in the Mitchell catchment. The Queensland Government's (Department of Environment and Science) Ground Cover Disturbance Index (GCDI) (accessed via the Queensland Spatial Catalogue) is calculated on a 25 m × 25 m raster for all ecosystem types in the Mitchell catchment (Data Inventory Table 41, Figure 97). Ground cover disturbance can only be calculated where the foliage projective cover ('tree cover') is less than 20%. It is also not possible to calculate ground cover disturbance for areas of water, or areas that exhibit low change (e.g., bare rock). Hence, the GCDI is most meaningful for relatively open rangeland ecosystems.

As described in the Data Inventory (Section 5.1.2), where GCDI can be calculated, a GCDI score is produced for each 25 m × 25 m raster by combining *mean ground cover* (over the period 1988–2009) classified into four categories (low, below mean, above mean, high) with *ground cover trend* (over the period 1988 – 2009) classified into four categories (decreasing, slight decrease, slight increase, increasing) to produce a GCDI score (Figure 32) ranging from 1 (High ground cover and increasing trend) to 16 (Low ground cover and decreasing trend). GCDI scores of 11–14 are taken to indicate a high level of ground cover disturbance. GCDI scores of 15 and 16 are taken to indicate a very high level of ground cover disturbance.

The percentage areas of each ecosystem type assessed for GCDI and the percentage of assessed area experiencing high or very high levels of disturbance are reported (Ecosystem Accounts Tables 10 & 19; Data Inventory Table 41). GCDI categories are also plotted spatially across the Mitchell's ecosystem types (Ecosystem Accounts Figure 38; Data Inventory Figure 98).

Note: Whilst GCDI can be regarded as a proxy for grazing pressure, inclusion of the trend term in the GCDI classification is problematic from an Ecosystem Accounting perspective as the intention in SEEA EA (and SNA) is that variables and indicators should respond rapidly to changing conditions.

1988 – 2009 Ground Cover mean

1988 – 2009 Ground Cover trend

Disturbance Level	High Ground Cover	Above Mean Ground Cover	Below Mean Ground Cover	Low Ground Cover
Increasing trend	1 – Very Low (Benchmark)	5 - Low	9 - Medium	13 - High
Slight increase in trend	2 – Very Low (Benchmark)	6 - Low	10 - Medium	14 - High
Slight decrease in trend	3 - Low	7 - Medium	11 - High	15 – Very High
Decreasing trend	4 - Low	8 - Medium	12 - High	16 – Very High

Figure 32. Ground Cover Disturbance Index scoring matrix.

9.4.4 Land clearing

[Ecosystem Accounts Tables 20 & 21; Data Inventory Section 5.1.3]

The following data from the Statewide Landcover and Trees Study (SLATS) (Queensland Department of Environment and Science, 2018) were used to inform levels of land clearing pressure for the Mitchell River catchment:

- Woody vegetation clearing data, measured as clearing rates in thousand hectares per year, for the clearing periods 1998–1991; 1991–1995; 1995–1997; 1997–1999; and then annually from 1999–2000 through to 2017–2018 (Ecosystem Accounts Table 20; Data Inventory Table 43).
- Woody vegetation clearing by replacement land cover (pasture, crops, timber plantation, mining, infrastructure, settlement), measured in thousand hectares per year, for the clearing periods 1998–1991; 1991–1995; 1995–1997; 1997–1999; and

then annually from 1999–2000 through to 2017–2018 (Ecosystem Accounts Table 21; Data Inventory Table 42 and Figure 99).

9.4.5 Pest animal and weed presence

[Ecosystem Accounts Tables 12 & 13, Figure 26 & 27; Data Inventory Section 3.3.3; Tables 21 & 22, Figures 44, 45 & 46]

As was the case for fire frequency and fragmentation, pest animal and weed presence can potentially be regarded as both a condition variable and an environmental pressure. Pest animals and weeds were identified for inclusion in the Environmental Pressures Account for the Mitchell catchment via the two-stage procedure described in Section 5.5.

The species richness of all priority invasive species (weeds and pest animals combined) present within 18.5 km × 18.5 km grid cells across the Mitchell River catchment is mapped in Figure 46 in the Data Inventory. Species richness, plotted for weeds and pest animals separately, is mapped in the Ecosystem Accounts as Figures 26 & 27, and in the Data Inventory as Figures 44 & 45, respectively.

The total area (in hectares) of each ecosystem type within which each priority invasive species has been reported to be present in the Mitchell River catchment is reported in the Ecosystem Accounts as Tables 12 & 13, and in the Data Inventory as Tables 21 & 22). As described in Section 5.5.2, areal presence is calculated based on overlaps between the 18.5 km × 18.5 km invasive species presence grid cells and the underlying polygon data used for mapping ecosystem functional groups.

The data show that priority invasive species are present across the entire Mitchell catchment, with total invasive species richness ranging from 1 to 23, with a median of 6 and a mean of 6.3 invasive species present within each 18.5 km × 18.5 km grid cell. The most widespread priority invasive species in the Mitchell catchment are feral pig, feral cat, wild dog and rubber vine, occurring across 99.98%, 99.96%, 99.92% and 98.74% of total catchment area, respectively. The least widespread priority invasive species in the Mitchell catchment are pond apple, sagittaria, and fire weed which occupy less than or equal to 0.04% of total catchment area, respectively. In total, 16 weed species occupy less than 1% of catchment area.

Rubber vine, cane toad, feral cat, feral pig and wild dog are present in all of the Mitchell catchment's ecosystem types. The aquatic invasive weeds cabomba, hymenachne, salvinia, sagittaria, water hyacinth and water lettuce are present in all aquatic ecosystem types. The ecosystem types in the Mitchell catchment that are impacted by the greatest diversity of priority invasive species are TF1.4 – *Seasonal floodplain marshes*, T3.1 – *Seasonally dry tropical shrublands*, *non-remnant*, T1.2 – *Tropical-sub-tropical dry forests and thickets* and T4.2 – *Pyric tussock savannas*. These ecosystem types have a priority invasive species richness of 30, 26, 25 and 26, respectively. The ecosystem types that appear to be least impacted by priority invasive species richness are MT2.1 – *Coastal shrublands and grasslands*, MFT1.2 *Intertidal forests and shrublands*, MFT1.3 *coastal saltmarshes and reedbeds*, and T5.1 *Semi-desert steppes*, which have a priority invasive species richness of between 4 and 6 (inclusive).

9.4.6 River disturbance

[Ecosystem Accounts Table 22, Figure 39; Data Inventory Section 5.1.6]

River Disturbance Index (RDI) values (Stein et al. 2002) for rivers and streams in the Mitchell catchment were obtained from the Bureau of Metrology website for assessment year 1998 (see Data Inventory Section 5.1.6 for further details). The RDI reflects disturbance due to anthropogenic processes (intensity and extent of human activities in the catchment, and modifications to the flow regime, with disturbance reported on a scale from 0 (‘wild’ or near-pristine) to 1 (severely degraded), all river segments in the Mitchell River catchment were found to have relatively low anthropogenic-induced disturbances, with the maximum RDI value reported at 0.595 (Ecosystem Accounts Table 22 and Figure 39, repeated from Data Inventory Table 45 and Figures 100 & 101).

Note: The RDI does not respond to the presence of invasive species and weeds, whereas AquaBAMM’s Aquatic Condition Assessment will – at least to some extent.

9.5 Supply and use tables in biophysical terms

[Ecosystem Accounts Chapter 6]

Data on the supply of ecosystem services by ecosystem types in the Mitchell catchment and their use by economic entities (businesses, households and government) in *biophysical* terms is estimated using the methodologies described in Chapter 7 of this document.

The ecosystem services listed in Table 21 were compiled for this purpose.

Table 21. Ecosystem services reported in the biophysical supply and use tables for the Mitchell catchment.

Ecosystem services		Ecosystem account table	Ecosystem account figure
	Supply and use: biophysical terms		
Provisioning services			
	Crop provisioning services	Tables 23 & 26	
	Grazed biomass provisioning	Tables 23 & 26	Figure 41
	Wild fish provisioning	Tables 23 & 26	
	Intermediate service: supply of juvenile banana prawns	Noted, but not quantified	
	Biomass provisioning: other wild animals and plants	Noted, but not quantified	Figure 45
	Water supply services: irrigation	Tables 23 & 26	
	Water supply services: household	Tables 23 & 26	
Regulating services			
	Carbon sequestration	Tables 24 & 27	
	Carbon storage: biomass	Tables 24 & 27	Figures 42 & 43
	Carbon storage: soils	Tables 24 & 27	Figure 44
	Soil & sediment retention	Tables 24 & 27	
Cultural services			
	Recreation-related services	Tables 25 & 28	(Figure 29 in this document)
	Visual amenity services	Noted, but not quantified	
	Education, scientific & research services	Noted, but not quantified	
	Spiritual, artistic & symbolic services	Noted, but not quantified	
	Other cultural services[1]	Noted, but not quantified	

[1]Includes, caring for Country, knowing that Country is being cared for, and passing on knowledge of how to care for Country to future generations.

9.6 Supply and use tables in monetary terms

[Ecosystem Accounts Chapter 7]

Data on the supply of ecosystem services by ecosystem types in the Mitchell catchment and their use by economic entities (businesses, households and government) in *monetary* terms is estimated using the methodologies described in Chapter 8 of this document.

SEEA EA-compliant monetary valuations of the ecosystem services listed in Table 22 were compiled for this purpose. In addition, the gross ecosystem product (in M$/year and in $/ha/year) supplied by each of the Mitchell's ecosystem types, the gross ecosystem product (in M$/year) from ecosystems in the Mitchell used by businesses, households and governments), and the gross ecosystem product for the Mitchell catchment overall (in M$/year) are reported in Tables 31, Table 33, and Figure 48 of the Ecosystem Accounts.

Table 22. Ecosystem services reported in the monetary supply and use tables for the Mitchell catchment.

Ecosystem services		Ecosystem account table	Ecosystem account figure
	Supply and use: monetary terms		
Provisioning services			
	Crop provisioning services	Tables 29 & 32	Figure 48 (in aggregate)
	Grazed biomass provisioning	Tables 29 & 32	Figure 48 (in aggregate)
	Wild fish provisioning	Tables 29 & 32	Figure 48 (in aggregate)
	Intermediate service: supply of juvenile banana prawns	Noted, but not quantified	
	Biomass provisioning: other wild animals and plants	Noted, but not quantified	
	Water supply services: irrigation	Noted, but not quantified	
	Water supply services: household	Noted, but not quantified	
Regulating services			
	Carbon sequestration	Tables 30 & 32	Figure 48 (in aggregate)
	Carbon storage: biomass	Tables 30 & 32	Figure 48 (in aggregate)
	Carbon storage: soils	Tables 30 & 32	Figure 48 (in aggregate)
	Soil & sediment retention	Noted, but not quantified	
Cultural services			
	Recreation-related services	Tables 31 & 33	Figure 48 (in aggregate)
	Visual amenity services	Noted, but not quantified	
	Education, scientific & research services	Noted, but not quantified	
	Spiritual, artistic & symbolic services	Noted, but not quantified	
	Other cultural services[1]	Noted, but not quantified	

[1]Includes, caring for Country, knowing that Country is being cared for, and passing on knowledge of how to care for Country to future generations.

10. Broader research questions

In addition to identifying and collating the required data and implementing appropriate methodologies to compile a pilot set of ecosystem accounts for the Mitchell catchment, Project 4.6 also addressed two broader research questions, as follows:

- Investigate whether SEEA EA-compliant condition indicators can be configured appropriately to report on the condition of interlinked ecosystem assets (e.g., rivers, floodplains and wetlands) in an environment that experiences considerable seasonal and inter-annual variability in rainfall and river flows
- Investigate whether mechanisms can be developed to produce meaningful SEEA EA-compliant valuations of cultural ecosystem services, particularly from an Indigenous perspective.

These research questions were addressed as explained in the following sections.

10.1 Detecting anthropogenic-induced change in the condition of interconnected ecosystem assets in environments with high inter-annual variability

Very careful consideration has been given within SEEA EA to approaches for identifying variables, indicators and indices of ecosystem condition (e.g., H. Keith et al. 2020 – and Figure 17 in this document – repeated as Figure 33 below for convenience). SEEA EA's condition assessment – and proposals for estimating assets' capacity to supply particular ecosystem services (Figure 33) – appears thus far to have focused on individual ecosystem assets, grouped into particular ecosystem types (e.g., floodplain wetlands). The Mitchell catchment is a setting in which capacity to supply important ecosystem services such as provisioning of wild fish biomass to the commercial barramundi fishery appears likely to depend on the extent and condition of a set of interconnected ecosystem assets (e.g., estuary, river channels and flood plain wetlands – in the barramundi example). Consequently, as part of Project 4.6, Dr Chris Brown and colleagues used data from the Project 4.6 Data Inventory and Ecosystem Accounts to investigate (i) whether a model-based approach using SEEA EA data could be used to detect change in the condition of a suite of interconnected assets and/or change in their ability to supply an ecosystem service (here provisioning of wild fish biomass to the commercial barramundi fishery in the Mitchell estuary), and (ii) how quickly the model-based approach could identify anthropogenically-induced change (as might be caused by water extraction for new agricultural irrigation areas) against a background of high natural inter-annual variability. The Abstract below summarises Brown et al's findings which emphasise the challenging nature of the problem. The full paper can be accessed via the pre-print link below.

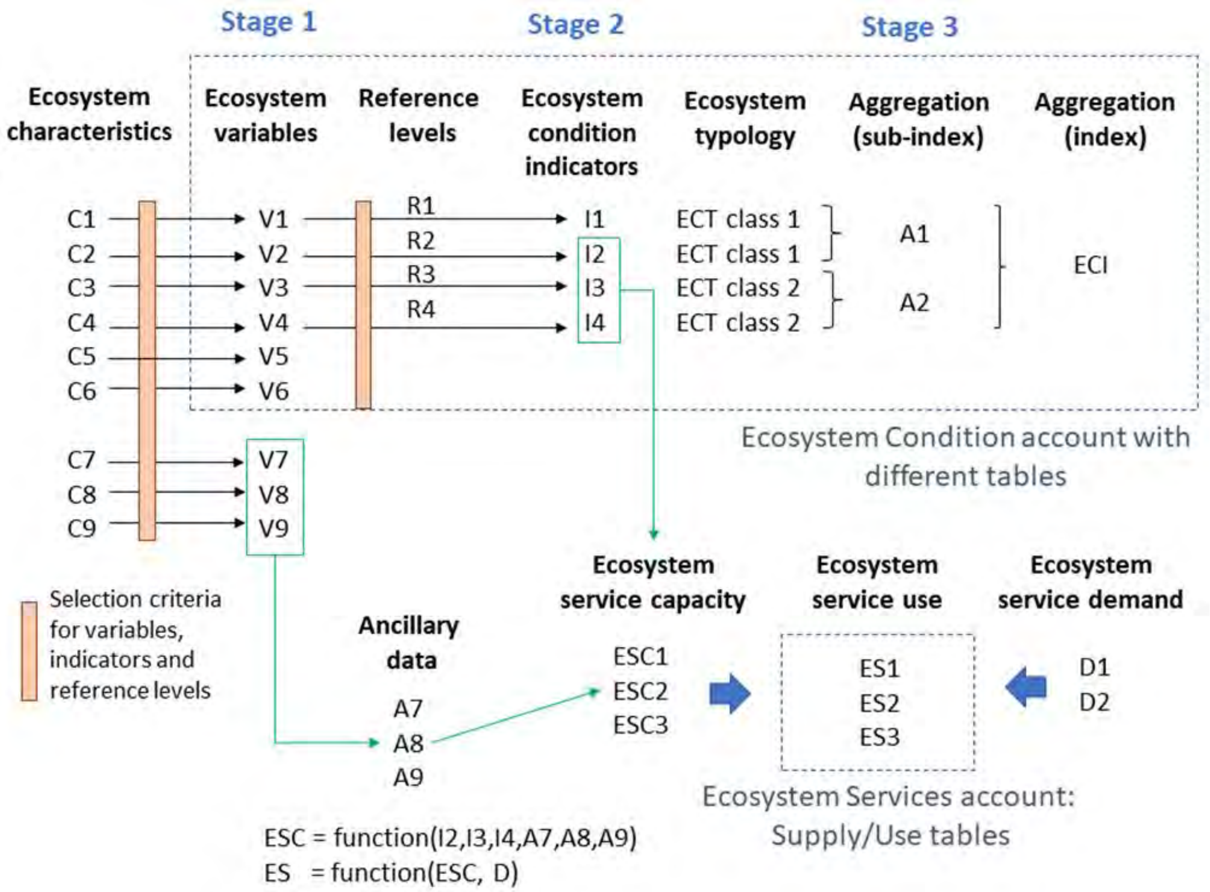

Figure 33. A framework proposed by H. Keith et al. (2020, p.15–17) for deriving an ecosystem condition index for reporting the health of the ecosystem, and for selecting variables, indicators and ancillary data to inform the capacity of an ecosystem asset to supply particular ecosystem services

Biorxiv link

biorxiv.org/content/10.1101/2021.07.19.453015v2

Pre-print title

Detecting change in interconnected ecosystem assets to inform indicators of condition in environmental economic accounts

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Abstract

Environmental Economic Accounts track the condition of interconnected ecosystem assets, to inform environmental decision-makers about its influence on the past and current status of ecosystem services. Indicators of condition need to be analysed to determine if they lead, are coincident with or lag environmental change, so that indicators are interpreted appropriately by decision-makers. Here we conduct performance testing of ecological condition indicators developed with the United Nations System of Environmental-Economic

Accounting – Ecosystem Accounting (SEEA EA) framework. We chose a case-study of a catchment-to-coast system with strongly interconnected assets and high natural variability, which likely confounds our ability to track long-term change. We first quantified covariation among ecological indicators for pasture biomass, vegetation greenness and barramundi catch per unit effort. Covariation in the indicators was driven by river flow, with higher values of all indicators occurring in years with greater river flow. Barramundi catch per unit effort was most sensitive to changes in river flow, followed by vegetation greenness and pasture biomass. We then defined reference bounds for each indicator that accounted for natural variation in river flow. We predicted the emergence times for each indicator, the time taken for each indicator to emerge from the background of natural variation. Emergence times were >10 years in all cases. Detecting change was more difficult where there were gaps in data. Ecosystem accounts can be used to compare ecological condition against performance objectives, but should consider natural variation in the system. National accounts are often used by decision-makers to directly inform near-term actions, because economic indicators respond rapidly to new policies and the prevailing economic conditions. We found that ecological condition indicators in highly variable ecosystems are lagging indicators of change, and as such should be used to assess historical performance, not as leading indicators of future change.

10.2 Methods for producing SEEA EA-compliant valuations of cultural ecosystem services

With the exception of recreation-related services, monetary valuation of cultural ecosystem services remains a major challenge for SEEA EA. As explained in detail in Sections 7.8.2, 8.4 and 8.4.2[53], there are two principle reasons why this is the case: (i) for consistency with national accounts, SEEA EA adopts an *instrumental value* paradigm within which *transactional exchange value* forms the basis for monetary valuation, and (ii) SEEA EA adopts a distinctly *linear* perspective on human interactions with ecosystems, focused on the flow of ecosystem services *from* ecosystems *to* human society. In contrast, Indigenous Traditional Owners' conceptualisation is reciprocal and relational, with *reciprocal* responsibilities between custodians and Country (e.g., Jackson et al. 2014; Strang, 2000). The values arising from those reciprocal interactions are grounded in the fundamental *relationship* between custodians and Country (e.g., Chan et al. 2016). Research from other parts of the world on *relational values* is challenging the uni-directional, individualistic and instrumental/utilitarian premise of the ecosystem services framework (Chan et al. 2016; Comberti et al. 2015; Díaz et al. 2018; Kenter, 2016).

With respect to Indigenous Australia, the labour and practices of Indigenous communities have been framed as the means by which some Australian Indigenous communities *co-produce* ecosystem services (Jackson & Palmer, 2015). The ontological category of 'nature' cannot be taken for granted as a source of ecological stocks and flows. Instead, Indigenous peoples *co-produce* with Country and the ecosystem services flow *from* that *relation*. The concept of *co-production* recognises that responsibilities under customary law require that custodians care for Country appropriately in order for Country to continue to provide

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[53] The material presented here is a summary of material that was presented previously in Sections 7.8.2, 8.4 and 8.4.2. Please refer back to those sections for a more expansive treatment of this topic.

ecosystem services. This *bi-directional* nature of the *relationship* between custodians and Country forms the basis for a reconceptualising of the interdependencies between custodians, Country and ecosystem service flows.

Given our understanding of the ways in which Indigenous peoples conceptualise socio-ecological relations (Jackson & Palmer, 2015), we acknowledge that Indigenous perspectives cannot be incorporated into SEEA EA in any straightforward way. The SEEA EA (White cover version) provides definitions of cultural ecosystem services that encompass 'services [that] may underpin people's cultural identity', together with a catch-all category of 'other cultural services' (United Nations et al. 2021; Table 6.3, p.131–134). Thus, SEEA EA's definition of cultural ecosystem services is sufficiently broad to accommodate the value (in the sense of an increase in wellbeing) that Traditional Owners derive from fulfilling their custodial responsibilities by caring for Country. Survey-based research by Larson et al. (2019) with the Ewamian people (Traditional Owners of land in the Gilbert and upper Mitchell catchments) found that 'Knowing that Country is being looked after' (Larson et al. 2019; p.89) can also be an important source of wellbeing for Indigenous people – beyond just those custodians who are involved on-ground in caring for Country. Thus, 'knowing that Country is being cared for' could be viewed as a cultural ecosystem service in its own right. The wellbeing that Indigenous people derive from knowing that Country is being cared for can be further enhanced by knowing that Country will *continue* to be cared for into the future. This is evidenced by the importance that Traditional Owners place on passing on knowledge of how to care for Country to younger generations. These conceptualisations of cultural ecosystem service value can all be accommodated within SEEA EA's descriptions of cultural ecosystem services, either via the link to cultural identity, or by introducing *caring for Country*, *knowing that Country is being cared for*, and *knowing that Country will continue to be cared for*, as cultural ecosystem services in the 'other cultural services' category. This latter approach is preferred as it makes reciprocal 'services to ecosystems' explicit as a value delivery mechanism within SEEA EA, and thus evidences the importance of the reciprocity and relational value to Traditional Owners.

Recognising these challenges, in Project 4.6 we considered two SEEA EA-compliant approaches that could potentially be used to provide a *partial* representation of the values that Traditional Owners and Indigenous communities might derive from *caring for Country*, *knowing that Country is being cared for*, and *knowing that Country will continue to be cared for*, as cultural ecosystem services. These approaches were: (i) a *cost of inputs* approach (akin to that used in standard national accounts for valuing provision of health services (i.e., 'caring for people'), and (ii) an *opportunity cost of outputs* approach. Section 8.4.2 describes these approaches in detail. The initial intention in Project 4.6 was to explore these valuation approaches, and collect relevant data, through workshop discussions and data collection with Traditional Owners and households in Kowanyama. Unfortunately, the intended Project 4.6 workshops were not held due to Covid-19 access restrictions. As we were unable to conduct workshops and discussions with the Kowanyama community, we do not know whether either of these valuation approaches – and the *partial* representations of the value of on-Country activities that they would produce – would be meaningful and acceptable to Traditional Owners and the Kowanyama community. Lacking the necessary dataset, and without an endorsement of the appropriateness (or otherwise) of the proposed methodologies from the Kowanyama community, we did not pursue these valuation approaches further in Project 4.6. The suggested methodologies remain, however, as opportunities for future collaborative research.

11. Reflections on compilation of ecosystem accounts

Compilation of a pilot set of SEEA EA compliant Ecosystem Accounts for the Mitchell catchment proved to be lengthy, detailed and challenging. This chapter provides some reflections on that process, from the perspectives of data collation and methodological development. The separate 'Ecosystem Accounts' report reflects on learnings regarding the potential use of ecosystem accounts for informing policy direction.

As far as possible, compilation of the pilot set of Ecosystem Accounts for the Mitchell followed the recommendations provided in the SEEA EA (White cover version) (United Nations et al. 2021). The intention set out in the SEEA EA (White cover version) is that all data reported in SEEA Ecosystem Accounts should be recorded in the same year, and that the full suite of Accounts should be updated regularly and frequently so that changes in ecosystem extent and condition, and in supply and use of ecosystem services, can be tracked through time. As the information base is still evolving, we included data from *different* years in the Mitchell's pilot Ecosystem Accounts to promote discussion about which data should be included, how data collection might best be synchronised, and how the Accounts might be updated most cost-effectively. As far as the authors are aware, this is the only major deviation from SEEA EA recommendations.

11.1 Data reflections

11.1.1 Ecosystem extent

Spatial polygon data (comprising more than 44,000 polygons) on Remnant Regional Ecosystems[54], categorised into Broad Vegetation Groups at 1:1,000,000 scale[55], were readily available for the Mitchell catchment via the Queensland Government's 'Queensland Globe' GIS data portal. Equivalent data will be available for compilation of extent accounts elsewhere in Australia.

11.1.2 Ecosystem condition

SEEA EA (White cover version) recommends that variables that are used to report on the condition of each ecosystem type should cover the full typology of abiotic, biotic and landscape characteristics (Figure 16 in this report and United Nations et al. (2021) Table 5.1, p.90). SEEA EA provides examples of condition variables for the different classes within each ecosystem typology characteristic (abiotic physical, abiotic chemical, biotic compositional state, biotic structural state, biotic functional state, landscape characteristics) for representative ecosystem types (United Nations et al. 2021; Table 5.7, p.106). Together with SEEA EA condition accounts in the literature, these examples were used as starting points in searching for appropriate condition variables to report on the six ecosystem typology characteristics for each of the Mitchell's 16 ecosystem types[56]. A long list of potential condition variables was compiled in this way. Variables from the long list were checked to determine whether data on each candidate condition variable were: (i) publicly

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[54] Remnant Regional Ecosystems data accessed via qldglobe.information.qld.gov.au
[55] qld.gov.au/environment/plants-animals/plants/ecosystems/broad-vegetation
[56] Different sets of condition variables can be used to cover the full spectrum of the SEEA EA Ecosystem Condition Typology for the different ecosystem types.

available, (ii) at comparable spatial resolution to individual assets within each ecosystem type, (iii) across the full extent of the relevant ecosystem type within the Mitchell catchment, and (iv) for the same year(s). This produced the set of ecosystem condition variables shown in the Stage 1 (Variables) Ecosystem Condition Account for the Mitchell's ecosystem types (Table 10 in Chapter 3 of the Ecosystem Accounts document).

Sourcing an appropriate and consistent set of ecosystem condition variables spanning the SEEA EA Ecosystem Condition Typology spectrum for the Mitchell's 16 ecosystem types to compile into a Stage 1 (Variables) Ecosystem Condition Account proved to be a lengthy and time-consuming process. This is likely to remain the case until SEEA EA ecosystem condition accounts become an established component of state governments' environmental reporting. Once this position is reached, expert advice from ecologists familiar with a state's ecosystem types, in combination with cost and practicality constraints on data collection, should have determined which variables are most appropriate for monitoring the required SEEA EA spectrum of ecosystem condition typology characteristics for relevant ecosystem types.

11.1.3 Supply of ecosystem services in biophysical terms

Provisioning services

Data on provisioning ecosystem services which are inputs to joint production processes that generate SNA benefits should, in principle, be relatively straightforward to obtain regularly and should also be updated relatively frequently. Supply of fish harvests as a provisioning ecosystem service into the commercial barramundi fishery provided the clearest example of this in the Mitchell. Catch data for vessels operating in the N3 commercial barramundi fishery are collected by the Queensland Department of Agriculture and Fisheries. These data are available at 30 nautical mile grid square resolution in the publicly accessible QFISH data base (qfish.fisheries.qld.gov.au). Catches of barramundi in QFISH 30-nautical mile grid squares AB12, AB13 and AC14 are considered Mitchell River-sourced fish (pers. comm. J. Robins, Queensland Department of Agriculture and Fisheries). Combined barramundi catches from these three grid squares were collated for the years 2010–2017, thus providing the data required to quantify supply of this provisioning ecosystem service (for each year individually, or – as presented in the Supply and Use Tables for the Mitchell in biophysical terms – as an average annual catch over the full period). Whilst this approach works well for a managed commercial fishery, equivalent data on total catch are very unlikely to be available for a recreational fishery, or for the catch taken for direct household consumption; this was indeed the case in the Mitchell. This pattern of data availability is likely to be repeated in other settings.

Even when catch data from a commercial fishery are available, spatial attribution of catch to specific ecosystem assets (grouped by ecosystem type) as the source of supply may be problematic. Attribution was straightforward for the commercial barramundi fishery in the Mitchell because it is an inshore gillnet fishery that operates primarily in the Mitchell delta channels or their immediately adjacent coastal zone. In contrast, attribution of supply of juvenile banana prawns (an intermediate ecosystem service) from the Mitchell estuary into the stock of adult banana prawns caught by the Northern Prawn Fishery operating offshore in the Gulf of Carpentaria would be much more difficult as the offshore stock receives juvenile prawns as intermediate ecosystem service flows from river catchments all along the Gulf's eastern coastline[57].

Supply of water services to households in the Mitchell is also relatively straightforward to quantify, using data reported annually by the relevant shire councils as the water suppliers. Obtaining data on the supply of water services from surface water sources to irrigated agriculture is more problematic. The total surface water-sourced volume supplied for irrigation from the Mareeba-Dimbulah Water Supply Scheme overall is readily available from Sunwater, the water supplier. However, only part of the Mareeba-Dimbulah Water Supply Scheme falls within the Mitchell catchment, the remainder being in the neighbouring Barron catchment. A straightforward split in proportion to area is confounded by the differing water requirements of the various crops grown. An approximate estimate of the irrigation water volume supplied to the Mitchell section of the Mareeba-Dimbulah irrigation area in any particular year can be constructed knowing the total volume supplied by the scheme overall in that year, in combination with remotely sensed data on the areas of different tree crops in the Mitchell and Barron sections (from the Australian Tree Crop Dashboard (University of New England: Applied Agricultural Remote Sensing Centre, 2022)), and estimates of average crop-specific irrigation requirements from Queensland DAF gross margin spreadsheets (business.qld.gov.au/industries/farms-fishing-forestry/agriculture/agribusiness/agbiz). The Mitchell catchment is unusual in containing areas of irrigated agriculture that are supplied from an irrigation system in a different catchment. Quantification of surface water irrigation supply in biophysical terms should be relatively straightforward in more standard settings where the water source and the irrigated areas are within the same catchment. Accurate quantification of irrigation sourced from on-farm groundwater bores is likely to be highly problematic; this was not a major issue in the Mitchell, however, because only relatively small areas of irrigated cropping in the catchment are supplied from groundwater (see Section 7.6.6).

In principle, an estimate of the overall quantity of grazing biomass supplied as a provisioning ecosystem service to cattle stations in the Mitchell can be constructed knowing average forage offtake per adult equivalent (AE) (McLennan et al. 2020), together with an estimate of the total size of the resident cattle herd (expressed in AE); however, Mitchell-specific cattle numbers are difficult to determine. Meat and Livestock Australia provide estimated numbers for the Northern Gulf Region as a whole, a portion of which can be allocated to the Mitchell based on the area of the grazing native vegetation QLUMP land use in the catchment relative to the Northern Gulf Region. It is difficult to gauge the accuracy of this estimate, however, as stocking densities are likely to vary between cattle stations.

Biophysical supply of crop provisioning services into irrigated production of avocado, banana, mango and sugarcane (the main crops, by area grown and total revenue) was also estimated for the Mitchell section of the Mareeba-Dimbulah Irrigation Area. SEEA EA (White cover version) recommends that the total crop harvested can be used as a proxy for supply of crop provisioning services when supply of individual services (e.g., soil nutrients, trace minerals, soil water) into the joint production process cannot be estimated separately. As was the case for irrigation water, total production per crop type is reported for the Mareeba-Dimbulah Irrigation Area as a whole through periodic publication of a Tablelands Agricultural Profile

[57] However, recent research by Broadley et al. (2020) has made progress in this direction.

(State of Queensland Department of Agriculture and Fisheries, 2010, 2015, 2019b). Avocado, banana, mango and sugarcane production was allocated to the Mitchell section of the Irrigation Area using remotely sensed data on the areas of different crops in the Mitchell and Barron sections (from the Australian Tree Crop Dashboard (University of New England: Applied Agricultural Remote Sensing Centre, 2022)). It is likely that biophysical data on crop production will be readily available for other locations; however, outside irrigation areas, this may be at relatively coarse spatial resolution. Local processing facilities for industrial crops (e.g., sugarcane, cotton) may be useful sources of total annual harvest data for local/regional areas.

Regulating services

As most regulating ecosystem services are public goods, they will not typically generate benefits that appear in the SNA. Consequently, it will not usually be possible to obtain data on the biophysical quantities of regulating ecosystem services supplied from market, or market-related, data[58]. Lacking direct data on the quantities of services supplied via markets, it is much more likely that *modelling* will be used to predict the quantity of regulating services supplied. This modelling will typically utilise data on the extent and condition of the ecosystem assets that are supplying the services, and on the scales and locations of the businesses, households and governments that benefit from those services (United Nations, 2022). Several modelling platforms are readily available for this purpose (e.g., ARIES (ARtificial Intelligence for Ecosystem Services) (Martínez-López et al. 2019; Villa et al. 2014), InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) (Hamel et al. 2015; Posner, Verutes, Koh, Denu, & Ricketts, 2016; Sharp et al. 2020), The Nature Braid (formerly LUCI (the Land Utilisation and Capability Indicator)) (B. Jackson et al. 2013; Trodahl et al. 2017). So too are evaluations and comparisons of their performance (e.g., Bagstad et al. 2018; Vigerstol and Aukema, 2011), with a recently published SEEA 'Guidelines' document providing a comprehensive overview (United Nations, 2022).

A substantial set of data on ecosystem extent, condition, and capacity to supply regulating services, together with socio-demographic and socio-economic data relating to demand for the services supplied, are required to drive these models. The SEEA Guidelines on Biophysical Modelling document provides suggestions for potential data sources in its Supplementary Information (seea.un.org/content/supplemental-materials-and-tables-guidelines-biophysical-modelling), drawing heavily upon remotely-sensed data sets – many with global coverage. These sources can be augmented with Australia-specific data from Digital Earth Australia (dea.ga.gov.au), particularly via their Open Data Cube (opendatacube.org) and specialised products that focus on specific ecosystem types (e.g., wetlands, mangroves). Consultation with relevant experts is advised to determine which data sources are most appropriate for providing locally relevant data to drive estimation of service supply from individual ecosystem assets.

Cultural services

As noted in Section 7.8, existing evaluation of cultural ecosystem services has focused mainly on recreation-related services, for which broad-scale data on visitation rates are often

[58] ACCUs generated from the carbon sequestration component of the global climate regulation ecosystem service are an exception.

available. If visitation rates to specific sites are known, then – depending on the scale and nature of the site – it should be possible to attribute numbers of visits to specific ecosystem assets or ecosystem types. Where visitation data are provided at relatively broad scale e.g., region or local government area, attribution to ecosystem assets or ecosystem types is more difficult, although rational attribution approaches can typically be constructed (as here for the Mitchell). Methods are also being developed to use social media data for this purpose (Arslan & Örücü, 2021; Goodbody et al. 2021; Teles da Mota & Pickering, 2020; Zhang, Huang, Zhang, & Buhalis, 2020; Zhang, van Berkel, Howe, Miller, & Smith, 2021).

Determining biophysical supply of other categories of cultural services is likely to be very difficult, although the potential use of social media data for this purpose is also being explored (de Juan, Ospina-Álvarez, Villasante, & Ruiz-Frau, 2021; Lee, Seo, Cord, Volk, & Lautenbach, 2022).

11.1.4 Supply of ecosystem services in monetary terms

Specific data are required to derive the exchange, or exchange-equivalent, prices that are applied to biophysical estimates of service flows to produce exchange-based valuations of ecosystem service supply and use in monetary terms. Here again, the challenges differ somewhat depending on the category of ecosystem service being considered.

Provisioning services

In line with SEEA EA recommendations (United Nations et al. 2021; Section 8.2), provisioning services which are inputs to joint production processes that generate SNA benefits will typically be valued by the residual value method. Data on the price of marketed outputs and relevant factor inputs (e.g., labour, fuel, fertiliser, agrochemicals) will often be readily available, either directly from the market or via gross margin estimation spreadsheets from state agricultural departments (updated if necessary by category specific inflation indices (e.g., Australian Bureau of Agricultural and Resource Economics and Sciences, 2021)). Data on the remuneration required by the business owner, and – particularly – data detailing the capital input required to establish the business (from which an annual user cost of capital can be determined) are usually much harder to obtain. Likely responses are either to use relatively broad-brush estimates for the missing data, or to avoid estimating ecosystem service values in monetary terms. These responses are problematic, however, as broad-brush estimations will lead to imprecision and inconsistency, whereas if exchange, or exchange-equivalent, prices are omitted this could lead to substantial under-reporting of gross ecosystem product and ecosystem asset value (if the intention is to construct a set of ecosystem asset valuation accounts (Figure 34)).

When using the residual value method to estimate an exchange price for ecosystems' input to the joint production process that produces irrigation water supply services from surface water irrigation schemes, it will be necessary to determine whether the pricing charged for irrigation water is sufficient to fully cover the operating, maintenance and periodic renewal costs of the scheme[59]. If this is not the case, then it will not be possible to produce an

[59] It is quite likely that irrigation water pricing will be insufficient to recoup the full capital cost of construction for surface water irrigation schemes. In these circumstances, the capital costs incurred have effectively been written off. Thus, the institutional setting suggests that it would not be appropriate to include these capital costs when applying the residual value method.

exchange-equivalent price for ecosystems' input(s) via the residual value method. This situation applied for the Mareeba-Dimbulah Irrigation Scheme.

Regulating services

SEEA EA (White cover version) provides guidance on valuation methods that can be applied within the SEEA framework to estimate exchange-equivalent values for regulating ecosystem services (United Nations et al. 2021; Sections 9.3 & 9.4). The type(s) of data required will vary depending on the valuation method being applied. The spatial resolution of the data required for location-specific implementations of these methods will vary depending on the spatial specificity of the service being supplied. For example, an avoided damage cost approach to produce an exchange-equivalent value for river flood mitigation services would ideally use data on damage costs (or a proxy) from the at-risk locations, whereas – as in the Mitchell accounts – an avoided damage cost approach for valuing the carbon storage component of the global climate regulating service could use the damage cost expressed via the social cost of carbon for either the Australian economy, or for the global economy as a whole. Where data for the relevant spatial locations are not available, benefit transfer will typically be used to produce an exchange-equivalent price. SEEA EA's requirement to use exchange values, as opposed to welfare values, requires that benefit transfer must be approached with considerable attention to detail if SEEA EA-compliant prices are to be obtained. This is discussed further in Section 11.2.4, below.

Cultural services

SEEA EA (White cover version) suggests that, where separate quantification of ecosystems' contributions to recreation-related services cannot readily be determined, visitors' expenditures can be used as a proxy for valuation (United Nations et al. 2021; para. 9.48, p.197). Data on visitor expenditures are provided at LGA resolution by Tourism Research Australia, although data are typically only available for localities with sufficient visitor numbers.

Data requirements for implementing the 'cost of inputs' and 'opportunity cost of outputs' methods that were proposed as potential approaches for producing exchange-equivalent valuations of caring for Country, knowing that Country is being cared for, and passing on knowledge of how to care for Country to future generations – as cultural ecosystem services relevant to Indigenous Traditional Owners and communities – were discussed earlier in Section 8.4.2.

11.2 Methodological reflections

Following on the reflections in the preceding section on data requirements for compilation of ecosystem accounts, this section offers some reflections on the methodologies applied to construct each account in the SEEA EA framework (as shown in Figure 3, repeated here as Figure 34 for convenience). The pilot accounts for the Mitchell comprise an Ecosystem Extent account, a Stage 1 (Variables) Ecosystem Condition account, and Ecosystem Services Supply and Use Accounts in Biophysical and Monetary Terms. An Ecosystem Monetary Asset Account was not compiled. The challenges inherent in constructing a monetary asset account are considered in Section 11.2.5, below.

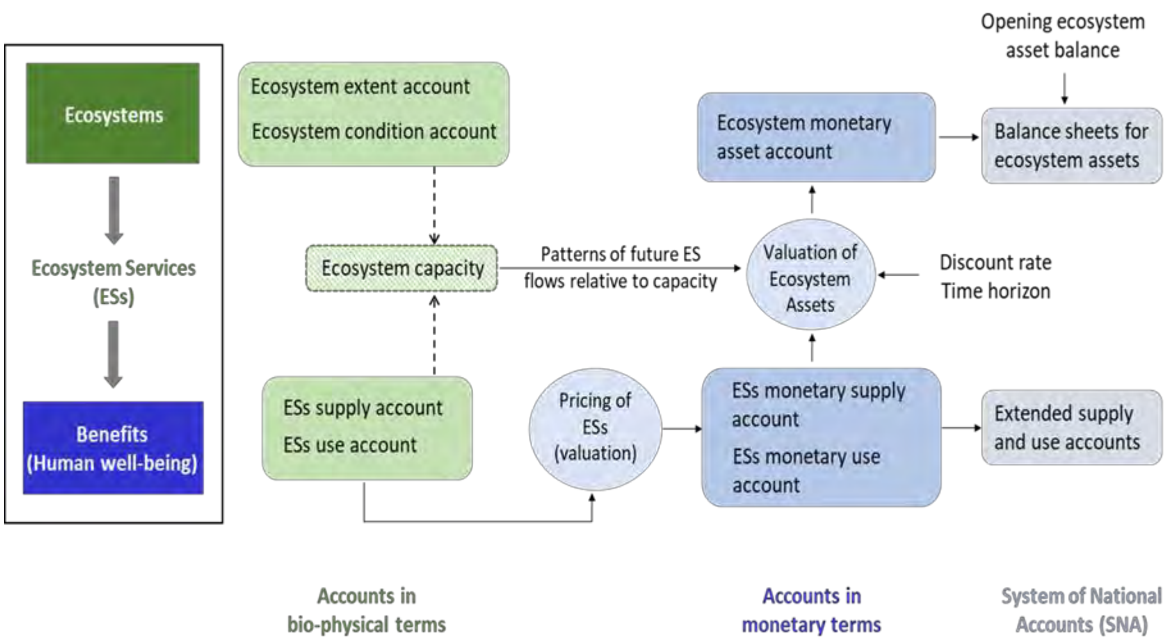

Figure 34. Biophysical and monetary ecosystem accounts within the SEEA EA framework, showing links to the System of National Accounts (SNA). (Adapted from Lai et al. (2018); Figure 1, p.53).

11.2.1 Quantifying ecosystem extent

The central methodology for constructing an ecosystem extent account is the cross-walk between the ecosystem types in the ecosystem mapping used for the ecosystem accounting area (for the Mitchell this was Remnant Regional Ecosystems (Neldner et al. 2020) under the Queensland Broad Vegetation Groups classification (Neldner et al. 2019)) and the equivalent ecosystem functional groups categorised under the IUCN's Global Ecosystem Typology (D. A. Keith et al. 2020). Expert advice is essential here. Project 4.6 is very grateful for the advice provided in this regard by Dr John Neldner of the Queensland Herbarium. Provided the cross-walk is undertaken carefully, it should be relatively straightforward to construct an initial extent account for an ecosystem accounting area. The extent account should be updated when the underlying mapping of ecosystem types is updated. For Queensland, the underlying mapping of Remnant Regional Ecosystems is updated bi-annually (Neldner et al. 2020)[60].

11.2.2 Estimating ecosystem condition

The pilot Ecosystem Accounts for the Mitchell contain a Stage 1 (Variables) Ecosystem Condition Account. As explained in Section 3.1, lacking normative interpretations and reference levels for many of the condition variables, a Stage 2 (Indicators) Ecosystem Condition Account was not compiled. Extensive consultation with ecologists familiar with the relevant ecosystem types will be required to establish the normative interpretations and reference levels required to progress to a Stage 2 (Indicators) Ecosystem Condition Account. In some instances, patches of habitat identified as being in pristine condition for different ecosystem types have been used as an empirical approach for determining levels of

[60] data.qld.gov.au/dataset/biodiversity-status-of-pre-clearing-and-2019-remnant-regional-ecosystems-queensland-series

condition variables that correspond to the upper end of the condition scale (e.g., Santos-Martín and Bruzón, 2021). This approach could usefully be applied in the Mitchell, potentially in collaboration with the catchment's Natural Resource Management Group.

11.2.3 Quantifying supply of ecosystem services in biophysical terms

Provisioning services

As explained in Section 11.1.3, biophysical supply of provisioning ecosystem services in the pilot Supply and Use Accounts for the Mitchell was either obtained directly from data (e.g., barramundi catch in the commercial fishery), or via straightforward construction from data (e.g., offtake of grazing biomass derived from estimated cattle numbers). Thus, biophysical supply of provisioning services was not linked back to the condition of the ecosystem assets that supplied the services. This 'missing link' to ecosystem condition is not problematic from the perspective of reporting provisioning services in the supply and use accounts. It would, however, have been problematic if the intention had been to compile an ecosystem asset valuation account in which the predicted supply of services into the future would have to be consistent with defined scenarios for climate, land management, economic development and socio-demographics in the accounting area (United Nations et al. 2021; Chapter 10).

This is challenging because the links between the condition of underlying ecosystem assets and biophysical supply of provisioning services that are inputs into joint production processes will inevitably be heavily confounded by multiple factors that influence aspects of the joint production process. Some confounding factors may be weather related (e.g., storms, droughts, soil moisture), others will be market related (e.g., cost of intermediate inputs, price(s) of output(s), availability of labour), and some will be stochastic (e.g., pest and disease outbreaks). In these contexts, substantial data sets and careful analysis will be required to reliably isolate the impact of changes in ecosystem condition on service supply, all else remaining equal. Furthermore, the effect of ecosystem condition might be relatively weak compared with other drivers of service supply. Where this is the case, the future scenarios for the 'other drivers' would have to be defined carefully and explored thoroughly via sensitivity analysis when future projections of service supply are generated to provide asset valuations for an ecosystem asset valuation account.

Regulating services

In contrast to provisioning services, many regulating services supply benefits to human society directly, rather than as an input to a joint production process[61]. In this situation, the link(s) between ecosystem condition and service supply might be expected to be easier to quantify. However, SEEA EA's requirement for users to be identified before supply of a service can be reported in ecosystem accounts means that supply of location-specific regulating services may be dependent on socio-demographic context as well as on ecosystem condition (e.g., human populations need to be resident downwind of forests that provide air filtration services before supply of that service can be reported in ecosystem accounts). Supply of services that regulate the impacts of extreme events (e.g., river flood

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[61] Human-induced environmental modifications to enhance carbon sequestration are an example in which a regulating service is provided via a joint production process. Supply of this service is thus subject to market factors such as costs of inputs and the price of the marketed output (ACCUs for the ERF's carbon market).

mitigation services, coastal protection services) will also be dependent on event occurrence. Global climate regulation services are, however, services for which beneficiaries can always be found, although the jurisdiction to which those beneficiaries are assigned could affect service valuation (as explained in Sections 8.3.1 and 11.1.4).

Noting the above, where relevant data are available (Section 11.1.3), modelling platforms such as ARIES (Martínez-López et al. 2019; Villa et al. 2014), InVEST (Hamel et al. 2015; Posner et al. 2016; Sharp et al. 2020), or The Nature Braid (formerly LUCI) (B. Jackson et al. 2013; Trodahl et al. 2017) are likely to be used to predict biophysical supply of regulating ecosystem services. McMahon et al's (2022) findings regarding the likely performance of an InVEST-type model in predicting supply of soil erosion control services in the Mitchell catchment suggest that, wherever possible, service supply predictions from these types of modelling platforms should be cross-checked against all available service supply data for the locality being modelled. Topic specialists (e.g., geomorphologists, hydrologists and soil scientists when considering soil erosion control services) should also be consulted to determine whether the models implemented in the commonly used platforms are appropriate for estimating supply of the relevant service in the accounting area being studied.

Cultural services

As was the case for provisioning services, supply of recreation-related cultural services in the pilot accounts for the Mitchell was quantified directly from estimated visitor numbers in the catchment's LGAs. SEEA EA's intention is to report supply of recreation-related cultural services to which ecosystem assets provide a contribution. When deriving the quantity of recreation-related services from visitor numbers to localities at moderate to coarse spatial resolution (as was the case in the Mitchell), it will be difficult to distinguish recreational visits to which ecosystems do make a considerable ecosystem contribution (e.g., rainforest tours, kayaking, recreational fishing) from those to which there is little or no ecosystem contribution (e.g., horse racing and motorsport meetings, stop-overs on journeys). This also makes it difficult to estimate the extent to which the quantity and/or quality of recreation service supply might be affected by varying ecosystem condition. Considerable research evidences that – in appropriate contexts – visitation rates and the quality of individuals' visit experiences are likely to be related to ecosystem condition (e.g., Crase and Gillespie, 2008; De Valck et al. 2017; Prayaga et al. 2010); however, to the best of the authors' knowledge these effects have not yet been quantified with the precision required for use in ecosystem accounts.

11.2.4 Quantifying supply of ecosystem services in monetary terms

Provisioning services

Whilst using the residual value method in the Mitchell Accounts to derive exchange-equivalent values for provisioning ecosystem services as ecosystems' contributions to joint production processes, several features of the method have become apparent. Firstly, as the value that will be attributed to the ecosystem service is the *residual* that remains after the returns to all other inputs to the joint production process have been accounted for, the valuation produced will likely be volatile as it is impacted directly by changes in the costs of all other inputs, and by volatility in the price of the marketed output itself (e.g., barramundi, avocado, sugarcane). This could lead to fluctuations in the value attributed – via the residual – to these types of provisioning ecosystem services from one iteration of the account to the next as the prices of agricultural outputs and key inputs (e.g., fertiliser, fuel, agrochemicals, labour) vary. Secondly, the residual value method sets quite stringent requirements for generation of a positive residual. Referring to Figure 31, a joint production process in which annual revenues from sale of the product (prior to interest payments and business tax) exactly matched the sum of:

- all fixed and variable costs incurred (including wages)
- the income level desired by the business owner(s)
- annual depreciation on all capital assets
- a return to capital equal to the prevailing government bond rate.

would generate zero residual. Consequently, in these circumstances, no value would be assigned to the ecosystem service input, although – in general terms – the business would likely be considered 'successful'. For higher risk businesses, rates of return to capital will have to considerably higher than the prevailing government bond rate to deliver the risk premium required to attract the necessary capital investment. Viewed from this perspective, ecosystem service valuations derived using the residual value method will typically be *higher* for ecosystem contributions to businesses with *higher* levels of risk. Provided that the costs of all other inputs are covered, a return to capital that is well in excess of the government bond rate will cover the risk premium, generate a substantial positive residual, and thus also a high valuation for the ecosystem service input(s). By definition, riskier businesses might be expected to deliver substantially higher returns in some years than in others. This will act to further increase the volatility of valuations of provisioning ecosystem services generated by the residual value method. Where stochastic events such as droughts, flood, pest and disease outbreaks are major factors influencing returns, this will likely make it particularly challenging to identify the influence of changing ecosystem condition on ecosystem service value (unless there is a strong, direct link between ecosystem condition and annual business return).

Regulating services

As noted in Section 11.1.4, where location-specific data for estimating exchange-equivalent prices for regulating ecosystem services are not available, it is likely that some form of benefit transfer will be used to derive the necessary price. Methodologies for benefit transfer continue to advance (see Johnston et al. (2021) for a recent update). However, SEEA EA's requirement to focus on exchange value means that valuation-derived pricing should only be transferred from prior studies that used valuation methods which generate *exchange values* (as opposed to welfare values). If benefits are transferred from individual studies, this will generally rule out transfers from valuations produced by the travel cost method, the second stage of the hedonic pricing method[62], contingent valuation and choice experiments.

Other frequently used sources for benefit transfer are meta-analyses of valuations of particular categories of ecosystem services (e.g., Johnston et al. 2017; Taye et al. 2021) and global collations of ecosystem service value estimates, of which de Groot et al's Ecosystem Service Value Database (by biome) is particularly comprehensive (de Groot et al. 2012). Meta-analyses and valuation databases must be used with care as sources for benefit

[62] The second stage of the hedonic pricing method is rarely applied (see Day et al. (2007) for an exception). The first stage of the method, which produces a marginal valuation of an environmental characteristic in a specific property market, *is* exchange value compliant.

transfers to generate prices for valuing ecosystem service flows in ecosystem accounts. Depending on the parameters included in their meta-regressions, it may, or may not, be possible to configure meta-analysis functions so that the valuation estimates they provide only draw on exchange-based valuations. Similarly, when accessing valuation databases, care must be taken to ensure that the representative average (or median) valuations that are produced prior to transfer only draw on valuations from exchange-value compatible methodologies.

Cultural services

Following the issues raised in the equivalent section on methods for quantifying biophysical supply of recreation-related ecosystem services, when using basic ‘per day’ or ‘per overnight’ data on visitor expenditures to value delivery of these services, it will generally not be possible to distinguish expenditures on recreational experiences that benefitted from ecosystem inputs from those that did not. This limitation will be difficult to overcome unless expenditure data from relevant ecosystem-related recreational experiences can be obtained separately.

Section 8.4.2 described how ‘cost of inputs’ and ‘opportunity cost of outputs’ methodologies could potentially be used to estimate some portion of the value that Traditional Owners and Indigenous communities associate with caring for Country, knowing that Country is being cared for, and passing on knowledge of caring for Country to future generations. However, these methodologies would have to be developed further in full collaboration with Indigenous communities and Traditional Owners before they could be considered appropriate for purpose.

11.2.5 Valuation of ecosystem assets

SEEA EA (White cover version) (United Nations et al. 2021; Chapter 10) provides comprehensive recommendations for construction of an ecosystem asset account in monetary terms (Figure 34). Asset values in a given year (e.g., t_0) are determined from the total net present value (NPV) of the ecosystem service flows that are expected to be supplied by that asset, in its t_0 condition, over a specified timeframe (e.g., 10 years) into the future. As a consequence, a considerable amount of data and modelling predictions have to be combined within a self-consistent set of biophysical, socio-economic and socio-demographic scenarios to generate an asset value account for an accounting area. The intention would be to apply the same methodology again to produce another asset valuation for the accounting area at a subsequent time (t_1), e.g., 5 years after the original t_0. The ‘asset value account’ would them comprise a balance sheet that reports the opening (t_0) and closing (t_1) values of the asset stock in the accounting area, and attributes changes between opening and closing asset stock values to ecosystem enhancement, ecosystem degradation, changes in valuation etc. The following steps would be implemented each time an asset valuation was produced, i.e., for each subsequent estimation of asset value:

- Self-consistent scenarios for biophysical and socio-economic/socio-demographic characteristics of the ecosystem accounting area would have to be constructed over the specified evaluation timeframe (e.g., 10 years into the future from current). These characteristics will influence future trajectories of asset extent, asset condition, service supply and service value. Biophysical characteristics such as temperature, rainfall, and the frequency and severity of storm events will affect asset extent and condition, and assets' capacities to supply ecosystem services. Socio-economic and socio-demographic characteristics such as population size, demographics, economic development pathways, market conditions for manufactured inputs and produced outputs, and societal demand for regulating and cultural ecosystem services will affect demand for and valuation of ecosystem services. Biophysical and socio-economic/socio-demographic scenarios would have to be consistent with one another to ensure that the future trajectories for ecosystem service values were plausible. A framework similar to that used to develop internally consistent climate and socio-economic futures for climate change research could be useful in this regard (Kriegler et al. 2014; van Vuuren & Carter, 2014).

- Appropriate modelling methodologies would then be applied to predict asset extent, asset condition and ecosystem service supply in biophysical and monetary terms for each year of the evaluation timeframe, forward from t_0 (e.g., predictions for 10 years forward from t_0) under consistent biophysical and socio-demographic/socio-economic scenarios. Modelling and data in combination would produce estimates of the value of the ecosystem service flows supplied by each ecosystem asset (typically grouped by ecosystem type) for each year of the evaluation timeframe, forward from t_0 (e.g., for each of the 10 years going forward from t_0).
- Annual discount factors would then be applied (at an appropriate real discount rate) to convert each future year's service supply to present value at time t_0. Present value service supplies would then be summed across each year of the evaluation time frame to determine the total NPV of all services supplied by each asset in the accounting area (potentially grouped by ecosystem type) (e.g., total NPV as the sum of all service values for each asset (grouped by ecosystem type) over an evaluation time frame running 10 years into the future from t_0). This provides the desired asset valuation at time t_0.
- The process would then be repeated at a later date, t_1 to produce NPVs for each asset running over the evaluation time frame forward from t_1, e.g., running 10 years into the future from t_1.
- Changes in the value of particular assets (likely grouped by ecosystem types) between t_0 and t_1 could then be decomposed into value changes due to price effects and value changes due to volume effects (United Nations et al. 2021; Annex 10.1, paragraphs A10.11 to A10.16). This would enable an opening (t_0) to closing (t_1) *balance sheet* to apportion changes in the value of the assets appropriately as either ecosystem enhancement, ecosystem degradation, ecosystem conversion, catastrophic losses, reappraisals, or revaluations (United Nations et al. 2021; Annex 10.1, Tables 10.5 & 10.6, p.229–230). This completed balance sheet would comprise the *ecosystem asset value account*, detailing opening asset values at t_0, closing asset values at t_1, and providing a breakdown of the changes between opening and closing values due to enhancement, degradation, conversion, losses, reappraisals and revaluations (United Nations et al. 2021; Annex 10.1, Table 10.8, p.233).

The procedure required to compile an asset value account is clearly specified in the SEEA EA (White cover version). However, reflections from compiling the pilot set of Ecosystem Accounts for the Mitchell catchment suggest that it will likely be challenging to produce an asset value account that would be useful for informing policy direction. The reasons for this are as follows:

- As described in Sections 11.2.3 and 11.2.4, it is likely to be difficult to identify statistically significant links between ecosystem asset condition and the biophysical supply and monetary valuation of many important provisioning ecosystem services. Furthermore, if statistically significant links can be identified, they may be relatively weak in comparison to other drivers. Section 11.2.4 indicated that valuations of provisioning ecosystem services that are inputs to joint production processes are likely to be volatile, year to year, due to fluctuations in the cost of other manufactured inputs, the price of the marketed output, or – typically when the residual method returns high valuations for ecosystem service inputs – high intrinsic volatility (i.e., 'high risk') in the joint production process itself. This suggests that for many provisioning ecosystem services, their contributions to asset NPVs are likely to be difficult to predict reliably into the future[63].
- Research by McMahon et al. (2022) in Project 4.6 concluded that the modelling approaches in commonly used ecosystem accounting modelling suites such as InVEST may produce misleading results when used to estimate supply of soil retention services in the Mitchell, unless they were closely informed by expert consultations and rigorously cross-checked against all relevant available in-catchment data. Findings of this type suggest that asset valuations that rely heavily on forward predictions of modelled biophysical service flows could be misguided, unless the suitability and local calibration of relevant models has been cross-checked very carefully.
- Research by Brown et al.[64] in Project 4.6, using the system of interlinked ecosystem assets that supply harvestable barramundi to the commercial fishery in the Mitchell estuary as an example, concluded that in settings like the Mitchell with high inter-year variability in key environmental parameters such as rainfall, it would take more than 10 years for a persistent human-induced change in condition to invoke a change in *biophysical* service supply that was large enough to be discerned convincingly from the background of natural inter-year variability. This suggests that it may well take several decades of consistent human-induced change before a change in the (likely more volatile) *monetary* value of service supply – and thus in asset value – could be discerned from natural- and market-induced inter-year variability. This could be problematic because it will likely be difficult to construct biophysical and socio-economic/socio-demographic scenarios that can reliably predict trajectories for ecosystem extent and condition, market prices for inputs and outputs, and demand for regulating services multiple decades into the future. In this context, over multi-decadal time frames, the asset values produced would largely be constructs of the scenarios, rather than arising primarily from the interacting dynamics of the accounting area's socio-ecological systems (e.g., Liu et al. 2007).

An asset value account was not constructed for the Mitchell because the Project 4.6 team did not have an adequate set of project-specific models for predicting biophysical and monetary service supply into the future, and – following findings from McMahon et al. (2022) and Brown et al. – were reluctant to use currently available ecosystem accounting modelling

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[63] The impacts of changes in asset extent on biophysical supply of services would probably be less volatile, but these changes in extent would also likely be heavily dependent on the selected biophysical and socio-economic scenarios.
[64] biorxiv.org/content/10.1101/2021.07.19.453015v2

suites for this purpose. Further development of ecosystem asset accounts and comparative evaluation of the use of available modelling suites for generating ecosystem asset accounts remain important areas for further research.

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Appendix A – Impacts of declining ecosystem condition on ecosystem services used by and supplied by the Indigenous community in Kowanyama

Aboriginal and Torres Strait Islander people should be aware that this Appendix contains the names of deceased persons who are cited as authoritative sources for land management practices and ecosystem extent and condition.

This Appendix contains information contributed by Indigenous Traditional Owners from the vicinity of Kowanyama in the Mitchell River delta. Information and data contributed by Indigenous Traditional Owners from the vicinity of Kowanyama and presented in this Appendix as written text, tables and maps remain the property of those Traditional Owners (or of their families in circumstances where they are deceased). Information and data contributed by Indigenous Traditional Owners from the vicinity of Kowanyama must not be reproduced from this Appendix, nor should these data be extracted and re-analysed in any way, without obtaining prior informed consent from the Traditional Owners through the Kowanyama Aboriginal Land and Natural Resource Management Office and Abm Elgoring Ambung RNTBC. Given the time constraints, a limited number of individuals and families were engaged in the provision of these data. This should not therefore be regarded as a comprehensive documentation of traditional land use.

Data collected in Kowanyama by Project 4.6 research associate Viv Sinnamon provide important insights into how supply of multiple provisioning, regulating and cultural ecosystem services by and to the Indigenous community in Kowanyama is being compromised by declining condition of ecosystems in the lower Mitchell catchment and the Mitchell delta. The primary pressures driving these declines are invasive weeds and feral animals, as detailed in the paragraphs below.

Shellberg et al. (2017) provide a recent summary of the biocultural diversity of the Mitchell delta wetlands, describing the prevailing situation as follows:

> *'The wetlands of the Mitchell Delta are in good to excellent health, due to the remote location and lack of intensive development pressures seen elsewhere in Australia and globally. However, the threats to the health of wetlands are numerous, and are increasing. Weed invasion is the largest current threat. Without heavy investments in large-scale weed prevention and control actions, weeds will fully transform the Delta over the next decade.'* (Shellberg et al. 2017: p.vi)

Culturally, wetlands are more than a source of traditional foods. Infestations by invasive weeds, particularly Olive *Hymenachne (Hymenachne amplexicaulis)* and feral *themeda (Themeda quadrivalvis;* Grader grass*)* are creating a new landscape. A 1994 Planning retreat for Kowanyama Elders at Mukarnt wetland, to provide guidance in the development of management strategies and the Kowanyama community's own land management agency, provided the following vision that expressed concern about future changes:

'We want to see our Country healthy. Waterholes still with water lily and lagoons healthy. We want to see our Country looking beautiful…...Like it was when we first had it. We don't want it to be run down and buggered up all together.

We want to make sure that young children say, this is what the old people used to tell us about.'

(Kunjen Elder. The Late Colin Lawrence) (Dale, A. and Kowanyarma Aboriginal Land and Natural Resources Management Office, 1994)

Changes to the delta landscape began with first European contact and the introduction of cattle and horses to the northern region late in the 1880s. An early example of change was the loss of the now locally extinct *Phragmites australis* (Common reed) beds that were said to cover hundreds of metres of coastal wetlands that included Long Swamp on the edge of Topsy Creek marine plains and Kowanyumal wetlands. *Yum thila* the phragmites increase site is located on a wetland there. References to large cane grass stands were made in oral history and reports from police patrols in the 1920s and are believed to be *Phragmites* stands. Cattle ate the nutritious young shoots out and later an increasing population of feral pigs ate the shallow rooted rhizomes. It is said there were two varieties of 'bamboo' in the old days. The variety that small bullet spears and children's toy spears were made from, and a second thicker-stemmed plant that was used in the manufacture of the lighter barbed and four-pronged fighting spears. Shafts made from *Phragmites* were lighter than standard wooden spear shafts (pers. comm. Jerry Mission, Jack Bruno and Patrick Eric, all deceased, 1980s). Supply of this woody biomass provisioning service has therefore been lost due to grazing pressure from domestic and feral animals (SEEA EA, 2021; Table 6.3 p.126).

Attempts to restore *Phragmites* to the Mitchell delta wetland are underway, with access recently obtained to *Phragmites australis* plant stock from a Pormpuraaw wetland for propagation and transfer to a nursery bed at the Kowanyama Culture and Research Centre. Attempts are now being made to reintroduce the plant from the established nursery bed to areas protected from predation by cattle and horses.

Horses have the ability to enter wetlands inaccessible to cattle and feral pigs due to the depth of early season wetlands and lagoons. Observations at Kowanyama are that horses have learnt to fully submerge their heads in search of the submerged seed pods of lily beds (mostly *Nymphaea gigantea). N. gigantea is* known locally as the seed lily and is the traditional source of grain for ground lily seed dampers. Additionally, feral pigs consume large quantities of bulgaruw (*Eliocharis*[65]) in the shallower waters of wetland margins. Grazing pressure from feral animals has therefore reduced supply of these wild plant provisioning services to the Kowanyama community (SEEA EA, 2021; Table 6.3 p.126).

The impacts of introduced hard hoofed animals have been identified in previous studies of the delta and includes serious pugging and disturbance of the soft margins of wetlands whilst gaining access to water plants (J. Shellberg et al. 2017). There is evidence of predation of long necked turtles (*Chelodina*), freshwater crabs (*Austrothelphusa*) and shellfish (*Velesunio*) by foraging feral pigs in the receding margins of drying wetlands, adversely affecting supply of wild animal and shellfish provisioning services (SEEA EA, 2021; Table 6.3 p.126).

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[65] *Includes Eliocharis dulcis*, *E. spacelata* and ors.

Other human-induced changes have occurred through the introduction of pastoral grasses and legumes that have led to loss of the diversity in the floral mosaic. This has brought adverse consequences for the related traditional burning regime in which early dry-season burning provides protection for fire-vulnerable species. This was a regime governed by the topographic and associated floral diversity of a large delta complex. Loss of key floral markers has impaired Traditional Owners' ability to implement this habitat maintenance regulating ecosystem service (SEEA EA, 2021; Table 6.3 p.129) which is itself an important aspect of caring for Country. Supply of caring for Country, knowing that Country is being cared for, and the opportunity to pass on knowledge of how to care for Country as cultural ecosystem services has also been impaired, reducing wellbeing benefits to Traditional Owners and the Indigenous community in Kowanyama as a whole.

Significant changes in ecological and habitat dynamics continue to occur due to invasive pastoral weeds. In the medium term it would appear the delta islands (Kokomnjen and Wallaby Island) will become the last stands of remnant native landscape, although even there introduced fauna such as feral cats, pigs and cattle have now begun to gain access.

Invasive weeds of particular concern, and their impacts on ecosystem condition and supply of ecosystem services, are detailed in the paragraphs following.

Grader grass

Themeda quadrivulvis

A range of impacts can be identified with the invasion of grader grass that illustrate the aggressively competitive nature of this pastoral weed, first transported to Kowanyama by machinery almost three decades ago. The grass has a similar impact to that experienced from Gamba grass in the Northern Territory. Grader grass is no longer restricted to roadsides and has been invading the savanna woodlands and grasslands of the delta with visible impacts over the last two decades. Invasion of the weed across the delta is now being assisted through increased motor vehicle ownership in Kowanyama and the resultant mobility across delta country away from the residential area of Kowanyama. Adverse consequences from grader grass infestations in specific ecosystems are:

<u>Loss of native Softwoods in open woodland</u>

The intensity and height of grader grass fires is seriously impacting species that are not fire resistant. Old hollow trees are gutted by fires and resident fauna that cannot escape are killed. Within living memory this decade has seen the loss of entire firestick stands and trees utilised for spear making along woodland and riparian areas of Magnificent Creek adjacent to Kowanyama (i.e., loss of woody biomass provisioning services (SEEA EA, 2021; Table 6.3 p.126)). An entire small grove of bush currant trees that provided children with bush fruit within walking distance of Kowanyama residential centre has been destroyed (loss of wild plant provisioning services (SEEA EA, 2021; Table 6.3 p.126)). Access through the surrounding densely grassed areas is now considered impossible.

The intense annual fires encouraged by the high fuel load of grader grass destroy the seeds and emerging young plants of the surviving flora and prevent the regeneration of woodland. Softwood species that are being lost from woodland as a result are:

1. Screw palm — *Pandanus spiralis*
2. Cabbage palm — *Corypha elata*
3. Kapok tree — *Bombax ceiba*
4. Turpentine tree — *Canarium australanum*
5. Currajong tree — *Brachychiton populneus*
6. Monkey nut tree — *Sterculia quadrifida*
7. Freshwater spear rod tree — *Cordia myxa*
8. Firestick tree — *Premna lignum vitae*
9. Bush currant — *Antidesma ghaesembilla*
10. White berry — *Flueggia virosa*

Loss of riparian and vine thicket species

In areas of grader grass infestation, late season intense burning of riparian and vine thicket associations are causing severe impacts. Initially thickets often associated with both riparian and small wetland drainage areas are subjected to the edge effects of fire and reduction in area. *Cathormium umbellatum* and *Strychnos lucida,* as thicket edge dominants, are succumbing to the annual effects of burning often surrounded by a sea of tall dry grader grass. In some places fires penetrate the thicket destroying the essential leaf fall that forms the underlying compost in the system. Riparian and vine thicket species at risk as a consequence are:

1. Notol — *Cathormium umbellatum*
2. Native strychnine tree — *Strychnos lucida*
3. Axe handle tree — *Mallotus phillipensis*
4. Pirrp — *Leea rubra*
5. Fire stick tree — *Premna lignum vitae*
6. Lolly Bush — *Clerodendron inerme*
7. Freshwater spear rod tree — *Cordia Myxa*
8. *Kapok tree* — *Bombax ceiba*

Supply of woody biomass provisioning services from these ecosystem is reducing as a result (SEEA EA, 2021; Table 6.3 p.126).

<u>Loss of native ground plants including a range of culturally significant species</u>

Grader grass is an aggressive competitor for ground space and is effectively displacing native ground cover that includes a range of traditional food plants, thus causing reductions in wild plant provisioning services from these ecosystems (SEEA EA, 2021; Table 6.3 p.126). The suite of impacted species with culturally significant values include:

1. Native cucumber — *Cucumis* — Food source
2. Native Gooseberry — *Physalis* — Food source
3. Native turnip — *Microstemma* — Food source
4. Blood root — *Haemodorum coccineum* — Fibre dye

Loss of established soft grass wetland margins

The fine grass margins of many wetlands associated with drainages of the delta that were previously often fringed with native *Themeda australis* (kangaroo grass) have now been invaded by *Themeda quadrivulvis* (grader grass). In some areas this has taken the weed to the very margin of rice grass (*Oryza*) and other sedges.

Low fine grass wetland margins provide resting areas for waterbirds in the wet season and were previously burnt when they dried as the dry season progressed. They dry earlier than fringing heavier grasses and provided access through Country following the wet season. Chains of wetlands and associated drainages created the traditional burnt mosaic.

With the intrusion and displacement of these native grasses by grader grass, very old stands of hollow coolabah trees are now being lost due to the intensity and height of the resultant fires. Shade trees and important habitat are being lost (loss of nursery and habitat maintenance regulating ecosystem services (SEEA EA, 2021; Table 6.3 p.128)).

Inhabitant species at risk that rely on habitat provided by the old hollow trees include:

1. Frilled necked lizard — *Chlamydosaurus kingii*
2. Brush tailed possum — *Trichosaurus vulpecula*
3. Native bees — *Trigonula hockingsii* and others
4. Hollow tree nesting birds

Loss of open grazing space and native food grasses is resulting in reduced ability to hunt wallabies (*Macropus agilis*) and diminishment of the wallaby population, a valued traditional food resource (loss of wild animal provisioning services (SEEA EA, 2021; Table 6.3 p.129) and associated elements of cultural identify that could be categorised as loss of spiritual, artistic and symbolic cultural ecosystem services (SEEA EA, 2021; Table 6.3 p.126)).

It is also suspected that the changes in grass diversity have resulted in the diminishment of the Northern nail tailed wallaby (*Onychogalea ungifera*) population and its habitat. The ‘Plain’s wallaby’ was the ancestral creator of *TuaR,* also known as Racecourse Swamp, a significant wetland of the region. Reductions in populations of these species therefore reduce community wellbeing by evidencing that Country is not being as well cared for as its Traditional Owners would wish.

Olive Hymenachne

Hymenachne amplexicaulis

Hymenachne is a semi-aquatic perennial grass that has become a major weed of northern Australia invading freshwater wetlands, flood plains and stream banks. Hymenachne is a Weed of National Significance and a declared weed throughout Australia.

Hymenachne was intentionally introduced into delta wetlands in the mid to late 1980s by a pastoralist at Kowanyama who was familiar with the concept of ponded pasture in south-eastern Queensland (pers. comm. The late Philip Yam, Olkola stock worker and Ranger KALNRMO). It is suspected that Para grass (*Urochloa mutica*) was also introduced at the same time. Some pastoralists still consider hymenachne a good fodder crop for their stock.

Kowanyama Aboriginal Land and Natural Resources Management Office (KALNRMO) became aware of the impact of the invasive weed species in areas of the Northern Territory such as the Arafura Wetlands. A survey of *Hymenachne* stands indicates establishment in key wetlands that have only this decade been reported by concerned Traditional Owners as it gained visibility after wet season growth. The weed invasion was described as 'looking like a corn patch in the swamp' (pers. comm. Alan (Monty) Gilbert Kokoberra Elder.). Four of the delta's iconic wetlands are now reported to have varying levels of infestation:

Thabvlang wvtaR	Kokoberra Swamp	15 27 05 S 141 38 22 E
Worpo	Ten Mile Swamp	15 22 38 S 141 42 23 E
TuaR	Racecourse Swamp	15 26 54 S 141 48 04 E
May Yel	Red Lily	15 26 58 S 141 39 54 E

There is now concern that, similar to grader grass, as Hymenachne is an aggressive competitor in native plant communities it has the potential to dominate and replace native species of water plants. Its dense growth and deep roots assist in its ability to colonise open water areas that are critical for the habitat needs of many species of plants and animals. North Australian wetlands are iconic key habitat for pied geese (*Anseranas semipamata*) and other waterbirds.

Concerns in relation to future impacts include:

- Density of growth will out compete other species of water plants, leading to their replacement, with the loss of significant resources and ecosystem services
- Density of growth of the pest grass will restrict access of pied geese hatchlings to food sources at distance from nests and other refuge areas.
- Displacement of *Oryza* and *Eleocharis* beds will diminish key food resources for adult geese during nesting time.
- Loss of refuge and open water landing areas for ducks and other water birds

Para grass

Urochloa mutica

Currently restricted to the town area of Kowanyama.

Water hyacinth

Eichornia crassipes

Currently restricted to the Leichardt Creek and Magnificent Creek system where it exits into saltwater. *Eichornia crassipes* was introduced into the area '*by an old Scottish lady*' in the early days from Dunbar where it was being used as a pretty garden plant as early as the late 1800s (pers. comm. The late Arthur White, Kowanyama Stock Overseer and lifetime resident of the Mitchell River Region). The hyacinth was introduced from South America into Florida, where hyacinth was given away at a public exposition in 1884; it very quickly became a pest thereafter. Dunbar Station was established the same year.

Now at:

May kal warrch	Fish Hole	15 27 46 S 141 48 04 E
Yiymanthuw	Yelco	15 28 31 S 141 49 30 E
PinpeR wataR	Kokoberra Swamp Dam	15 26 43 S 141 38 36 E

Eichornia crassipes was introduced into these wetlands during the Mission era under the mistaken idea that it was a plant that 'cleared the water'. The Kowanyama Land Office took part in trials to test biological controls for the pest in the form of two weevils that had proven successful elsewhere. Two varieties of Water Weevils *Neochetina eichorniae and Neochitina bruchii* [66] were introduced for trial during the early 1990s at *Yiymanthuw and May kal warrch*. They were relatively sheltered locations, chosen carefully to allow colonies of the weevils to establish. At the time the Land Office was working on weed issues with the Tropical Weeds Research Centre in Charters Towers (Pers. comm. Joe Vitelli and others, some of whom assisted in a weeds workshop at Kowanyama and Rutland Plains Station in 1991.).

Hyacinth remains rampant across the region.

[66] See: mottled water hyacinth weevil (ufl.edu)

Appendix B – Seasonal utilisation of ecosystem assets for supply of provisioning ecosystem services to the Indigenous community in Kowanyama

Aboriginal and Torres Strait Islander people should be aware that this Appendix contains the names of deceased persons who are cited as authoritative sources for land management practices and ecosystem extent and condition.

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The wet season

The wet season in Cape York Peninsula and the Mitchell River delta brings a whole new suite of bush foods to the local economy. The region becomes one huge wetland that restricts access to outlying regions. All forays onto Country during the wet season are on foot and areas utilised are outside the township area. Many places further afield are not accessible due to the numerous flooded waterways of the delta.

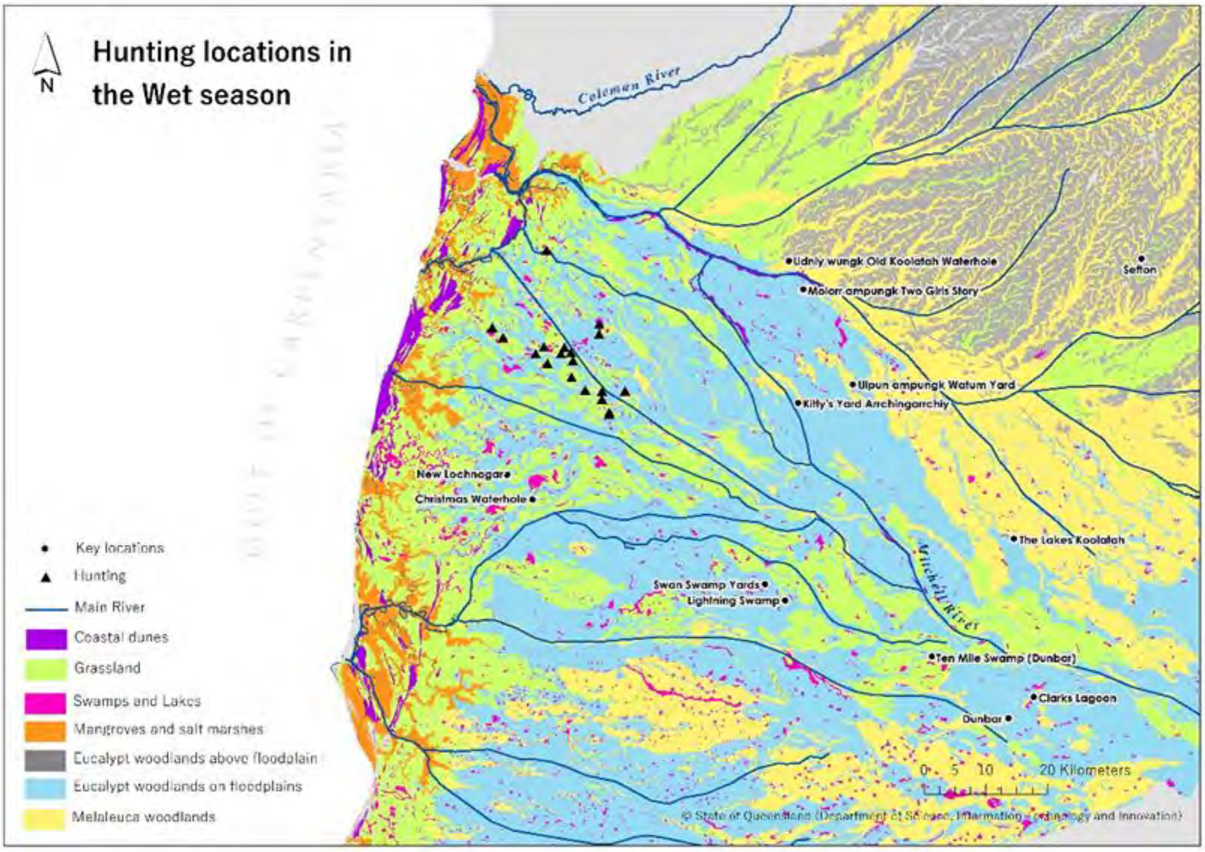
As the creeks around the township fill with the monsoon rains and the wetlands are replenished, pied geese (*Anseranas semipalmata*) gather to build their nests in the rice grass (*Oryza australiensis*) and bulguruw (*Eliocharis dulcis* and ors) beds. The waterbirds gather to harvest emerging freshwater crabs (Unidentified *Austrothelphusa*) and swamp snails in preparation for gathering at the rookeries closer to the coast.

Aestivating long necked swamp turtles (*Chelodina expansa*) emerge from their hibernation in the softening wetlands. This is a time when turtles are taken as they lie visible in the softened ground, 'back open' to discovery by groups of women, whistling kites, sea eagles, other raptors, and feral pigs.

With the fresh run of floodwaters in the creeks, eel tailed catfish known locally as jewfish (*Neosilurus*), spangled perch (*Leiopotheropon unicolour*), fork-tailed catfish (*Arius sp.*) and turtles (*Chelodina expansa and Emydura australis*) are caught on handlines close to town. Barramundi are also taken.

Agile wallabies (*Macropus agilis*) fatten with the new grass growth but become increasingly difficult to hunt in the long grass, and with the closure of access roads during the wet season. Dogs are used for hunting feral pigs by the men both with rifles and without. The meat is cooked in ground ovens or taken into town uncooked.

By late to mid-February the geese are nesting and groups gather the fragile eggs for transport into town wrapped in grass. Eggs are eaten fresh and with young chicken. Brolga (*Grus rubundicus*) and Sarus Crane (*Grus Antigone*)[67] nests of eggs on the wetland margins are not generally gathered for traditional reasons, only being eaten by senior men. To avoid the abandonment of nests by nesting birds, water is splashed over the nest to remove human smell and sometimes some eggs are left to encourage replenishment by nesting birds.



FigureB1: Resource hunting locations, by ecosystem types, for fish and animals used by Indigenous hunters from Kowanyama during the wet season. Data collected by Viv Sinnamon using information from Indigenous Traditional Owners in Kowanyama and surrounding areas. Information and data presented in these maps remain the property of the Traditional Owners (or of their families in circumstances where they are deceased). Information and data from these maps must not be reproduced, nor should data be extracted and re-analysed in any way, without obtaining prior informed consent from the Traditional Owners through the Kowanyama Aboriginal Land and Natural Resource Management Office and Abm Elgoring Ambung RNTBC. Given the time constraints, a limited number of individuals and families were engaged in the provision of these data. This should not therefore be regarded as a comprehensive documentation of traditional land use.

[67] Both cranes are claimed to be native to the delta *G rubundicus: Minh Kurr'urrl* and *G Antigone Minh pulpal*. Pers. Com. Jerry Mission 2000

The dry season

As the dry season progresses and the delta begins to drain, access becomes easier and travel further afield becomes possible both on foot and by motor vehicle, albeit the main Mitchell and Alice Rivers restrict access for a time to remoter areas to the north and east.

Vehicle transport allows access to more distant destinations on neighbouring Rutland, Dunbar and Koolatah Stations once the roads are open to traffic. Both the *Errk Oykangand National Park* (*Aboriginal Lands*)[68], Oriners and Sefton[69] are periodically visited by Top End or freshwater clan groups and their associated families. This area is renowned for its prolific turtle (*Chelodina expansa*) and Sooty Grunter (*Hephaestus fuliginosus*) population.

As winter approaches water birds are fledging and the wetlands become a source of young flightless pied geese, prized for their fat tender flesh. The young waterbirds of the delta rookeries begin to fly from their nests to feed in the nearby wetlands.

As the wetlands recede turtles are found by women and their families in the weed and grass margins. As the areas progressively dry, turtles are located by the small air hole mound where they are buried in the hard and drying mud. Others (*Chelodina expansa and Chelodina longicollis*) are opportunistically discovered as they migrate from drying areas of swamps and watercourses throughout the dry season.

Traditionally, Mitchell River delta people did not use canoes, however coastal and inland freshwater fishing remains a significant contributor to the diet of Kowanyama. Only a couple of people have small boats and motors and an increasing number of fishers prefer fishing with rods.

During the season turtles and fish are taken by hand line in freshwater streams and waterbodies across the region. The freshwater shellfish (*Velesunio wilsoni*) are taken opportunistically for consumption as well as for bait. Rarely are the long fluted shelled mussel (*Velesunio unidentified*) of the wetlands taken. Freshwater swamp crabs (*Austrothelphusa prob. transversa*) including the Tiger Crab of inland forest Country (*A. tigrina*) were traditionally taken, but are no longer considered a food resource.

The shark season, marked by the flowering of the shark lily (*Crinum*), heralds the end of the dry and the coming of the wet season. Sharks (*Cacharinus leucas and C. limbatus*) migrate into rivers late in the season in anticipation of the coming of first rains. Sharks were traditionally caught on short fishing poles, bark fibre lines and wooden shanked bone tipped hooks. Modern heavy handlines are used now. The short line and wooden rod placed the person fishing close to the water and prone to fatal crocodile attack. Fatalities historically occurred during shark season. The longer handlines provide greater protection from saltwater crocodile attack. Sharks are considered desirable when they fatten and their liver fat becomes white. Large numbers of small sharks are caught and prepared into the traditional fish meal cakes. The large white livers are kept for further cooking and consumption of the fish 'dampers,' similar to stingray (*Himantra*). Rays are speared in the surf shallows on the low incoming tide. The flesh of both is squeezed of fat and juices in salt

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[68] Under the Joint management of Traditional Owner Groups, *Abm elgoring ambung* Native Title Prescribed Body Corporate and QLD National Parks and Wildlife Service.

[69] Oriners (Helmsley Holdings) and Sefton cattle stations were purchased by Kowanyama Aboriginal Council in the 1990s.

water. This traditionally allowed the dry cakes to be kept for several days before the modern days of refrigeration and extended stays on the coast. The yellow mouth of a stingray indicates a fat fish.

Mud crabs (*Scylla serrata*) are taken regularly by spear, line and crab pot throughout the year and remain a highly valued catch both within estuaries and along the shoreline. In good seasons catches can be as high as 7 male crabs per pot by those owning vehicles and able to access coastal areas to set and check pots. Most people would set no more than two or three crab pots. One or two set pots is more common with the equipment being high maintenance due to snags and crocodile damage. Mud shell (*Geloina coaxans*) are gathered in the mangroves of the small drainages off the main creeks and rivers. The shells are cooked on the coals or taken home to boil for soup, and occasionally used for bait. The soup is valued for its medicinal properties and its ease of consumption by the elderly. Only occasionally are mud whelks (*Telecopium Telescopium*) taken for bait or food.

As the mangroves and other trees flower, flying foxes (*Pteropus alecto*) fatten on the nectar. They are taken in large numbers mostly by men. As many as 70 animals are prepared in traditional ground ovens for families in town.

An important event that in traditional times attracted large numbers of people from afar to gather for the ceremonies[70] is associated with the taking of large numbers of fish in late season drying lagoons. Large numbers were required to both gather the plant material required for the stunning of fish, to gather the floating fish and to consume the huge amounts of fish gathered. Gathering of the fish was overseen by senior men of the ceremony. Excess fish were prepared into squeezed dried fish cakes for the journey back to homelands following the ceremonies, trading of goods and the finalisation of other traditional matters. Earlier hoop nets, leaf bundles and fish traps have been replaced by the modern bait net.

The imperative for this major cultural event was to precede the numerous waterbirds eating all the easily caught fish in the rapidly shallowing waters. A squadron of pelicans are capable of successfully competing for fish against other birds. 'Fish Hawks,' Brahminy Kite (*Haliastur indus*), Sea Eagle (*Haliaetus luecogaster*) and Osprey, (*Pandion haliaetus*) hovering overhead easily seize the larger fish.

Traditionally the call of the Whistling Kite (*Haliastur sphenurus*) was mimicked on lagoons when spearing turtles and file snakes. The whistle attracts the turtles and file snakes (*Acrochordus arafurae*) to the surface and certain death by spear.

In more modern times fish bait seine nets have replaced the use of bundled bushes and spears. 'Crayfish time' is an annual late season harvest, similarly out to beat the waterbirds. Red claw crayfish (*Cherax quadracarinatus*), large freshwater prawns (*Macrobrachium rosenbergii*), catfish (Arius), turtles, large spangled perch (*Leiopotherapon unicolour*) and the occasional freshwater crocodile (*Crocodilus johnsonii*) are taken by net. Saltwater clan groups have traditional restrictions on the eating of freshwater crocodiles. Freshwater *Uw Oykangand* and *Olkola* groups eat the crocodile with some restrictions relating to the age of the consumer. Only eggs of the saltwater crocodile (*Crocodilus porosus*) were ever eaten on the lower delta, but they are now consumed only rarely, due to difficulty of access to nesting

[70] *Pinpan*, *Pinpernt* and *Idnban* ceremonies (The equivalent in *Yir Yoront, Kokoberra and Kunjen* languages all associated with ancestral waterbirds and their taking of fish within the Mitchell River mega delta).

sites in mangrove forests. The saltwater crocodile meat was not eaten. A senior man noted that there are now more saltwater crocodiles than in his youth when people were still living in the bush away from the Mission and ate their eggs.[71]

There is a permanent prohibition on the consumption of emu (*Dromaius hollandiae*) and use of emu products, including the feathers. In traditional bush times the handling of emu bone tools and emu bone pointed spears were prohibited to non-initiates. Anyone who does did not handle children until they were walking and strong.

It is suspected that more than two decades ago the high population of agile wallabies (*Macropus agilis*) in the delta was subject to an unidentified virus that decimated wallaby numbers. The incursion of the rampant introduced grader grass (*Themeda quadrivalvis*) around the same time now threatens the native habitat of large areas of the delta. Grader grass is overtaking the native fine grasses and herbs that are preferred by the surviving wallaby population. Native edible species are being replaced rapidly by the pastoral weed as a result of aggressive competition and the intensity and height of grader grass fires in late season[72]. Wallabies and other game are now difficult to see in many woodland and grassland areas due to the height and density of the introduced grass. There was traditionally a time of long grass when sighting the animals was difficult before the 'knock down' wind and rain of the late wet season, but never to the extent of the grader grass infestation of recent decades. Those hunting wallabies do so on nearby cattle stations with rifles and the permission of station managers. Bush kills of 'bullock'[73] and feral pigs have filled that significant gap in locally hunted food supplies. Kills are cooked in ground ovens out bush (Kub murris) covered by sheets of melaleuca bark (*M. dealbata, M. argentea or M. leucandenron*) or galvanised iron.

The goanna population, including blue tongued lizards (*Tiliqua scincoides*), appears to be recovering following the introduction of cane toads (*Rhinella marina*) from Chillagoe[74] in the 1960s with the misguided intention of controlling snakes. Goannas have retaken their place as good bush tucker (Sand goanna, *Varanus Panoptes* and occasionally Water Goanna, *Varanus mertensis*). The Wanguw or tree goanna (*Varanus tristis*) is rarely a source of food and not hunted.

Large and successful catches are shared among families. This includes feral pig, bullock, wallaby, bats, barramundi (*Lates calcarifer*), red claw crayfish (*Cherax quadricarinatus*) and bull and black tip sharks (*Carcharhinus leucas* and *C. limbatus*). Several households share the benefits of a day's hunting. A recent two day catch of early season barramundi by five young men amounted to 17 fish, an estimated 70 kilograms in weight.

Plain turkeys, Bustards (*Ardeotis australis*) fatten on grasshoppers and turkey fruit (*Grewia latifolia*) and are fattest as winter sets in, and some plains Country has been burnt. Turkeys are highly valued and are only taken occasionally. Other bush fruits and small animals are

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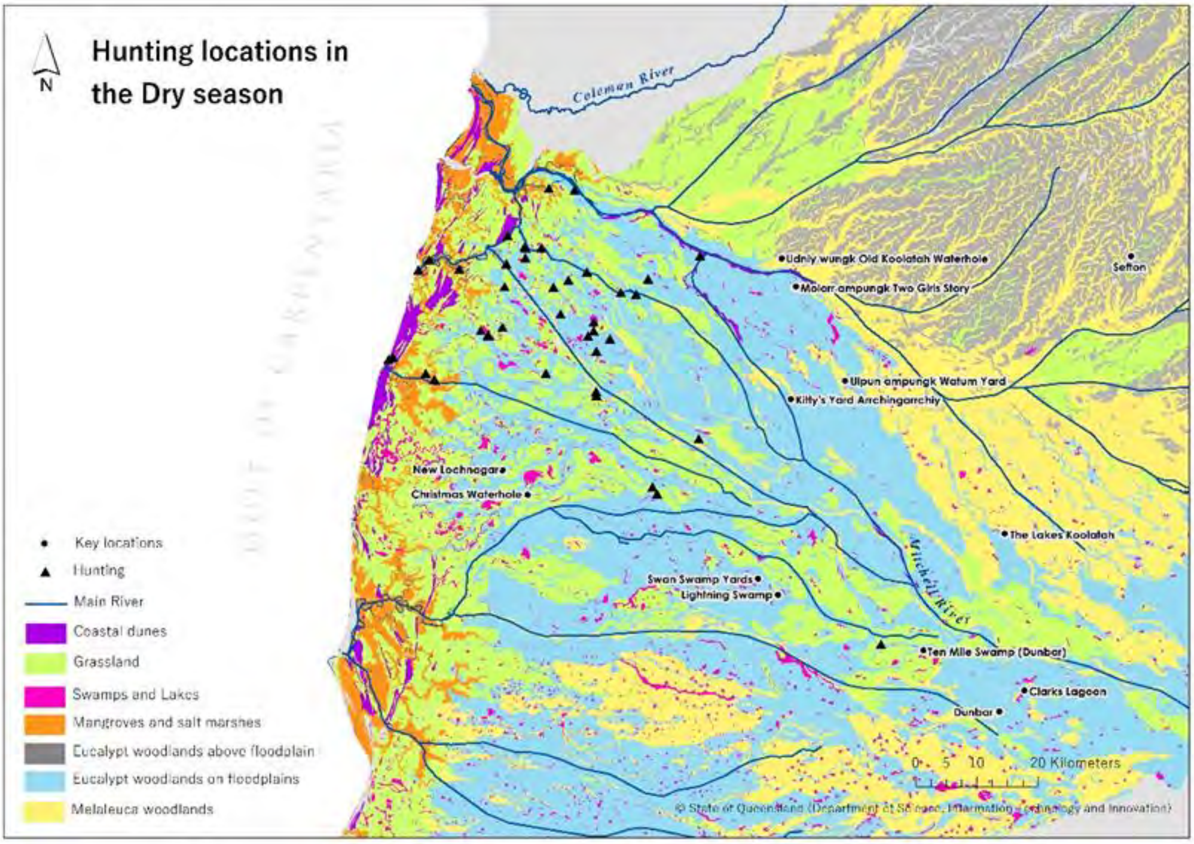
[71] Jerry Mission Pers. Com. 2002

[72] Native gooseberry (*Physalis minima*), Native turnip (Unidentified *Microstemma sp*) and native cucumber (*Cucumis trigonus*). White berry (*Securinega melanthesoides*) and bush currant (*Antidesma ghaesembilla*) trees are also succumbing to the altered fire regime.

[73] Particularly following the financial collapse of the Kowanyama Cattle Company and uncertain ownership of unmanaged stock and restricted to the Kowanyama Aboriginal Land area.

[74] Pers. Com. "A flour drum full", Peter Michael and Arthur White.

opportunistically taken providing a varied diet, part of the significant contribution of traditional bush foods to the subsistence economy at Kowanyama. Unfortunately, bush fruit from open forest lands, as described, is being displaced by grader grass as its invasion front advances and the availability of these foods decreases to only small pockets.



FigureB2: Resource hunting locations, by ecosystem types, for fish and animals used by Indigenous hunters from Kowanyama during the dry season. Data collected by Viv Sinnamon using information from Indigenous Traditional Owners in Kowanyama and surrounding areas. Information and data presented in these maps remain the property of the Traditional Owners (or of their families in circumstances where they are deceased). Information and data from these maps must not be reproduced, nor should data be extracted and re-analysed in any way, without obtaining prior informed consent from the Traditional Owners through the Kowanyama Aboriginal Land and Natural Resource Management Office and Abm Elgoring Ambung RNTBC. Given the time constraints, a limited number of individuals and families were engaged in the provision of these data. This should not therefore be regarded as a comprehensive documentation of traditional land use.

Appendix C – Significant cultural values associated with the Mitchell delta wetlands

Aboriginal and Torres Strait Islander people should be aware that this Appendix contains the names of deceased persons who are cited as authoritative sources for land management practices and ecosystem extent and condition.

This Appendix contains information contributed by Indigenous Traditional Owners from the vicinity of Kowanyama in the Mitchell River delta. Information and data contributed by Indigenous Traditional Owners from the vicinity of Kowanyama and presented in this Appendix as written text, tables and maps remain the property of those Traditional Owners (or of their families in circumstances where they are deceased). Information and data contributed by Indigenous Traditional Owners from the vicinity of Kowanyama must not be reproduced from this Appendix, nor should these data be extracted and re-analysed in any way, without obtaining prior informed consent from the Traditional Owners through the Kowanyama Aboriginal Land and Natural Resource Management Office and Abm Elgoring Ambung RNTBC. Given the time constraints, a limited number of individuals and families were engaged in the provision of these data. This should not therefore be regarded as a comprehensive documentation of traditional land use.

This appendix provides a brief illustration of the close association that the people of Kowanyama have with their Country within a vast delta landscape of wetlands. It does not intend to provide an exhaustive account of the delta cultural landscape but provides indicative examples of how associations between people and Country enhance wellbeing. In the context of Project 4.6, these benefits to wellbeing of individuals and the community as a whole could potentially be categorised as cultural ecosystem service benefits that arise from caring for Country, knowing that Country is being cared for, and knowing that knowledge of how to care for Country is being passed on to emerging generations. Shellberg et al. (2017; p.vi) set the scene as follows:

> *'The Mitchell River Delta in northern Australia is the ancestral and current home of the Kokoberra, Kokoberrin, Yir Yoront, Yir Thangedl, and Kunjen Aboriginal People. They have managed and been supported by the Delta's freshwater wetlands and coastal waters of the Gulf of Carpentaria for thousands of years. Today, 1000 Aboriginal People from these linguistic groups live in the community of Kowanyama with strong connections to Homelands across the Delta and beyond.'*

Many wetlands are associated with creation stories and increase sites of significance across Mitchell River delta country. The neighbouring cattle station, Rutland Plains, is located on the banks of a permanent lagoon. Rutland Plains lagoon is known as *Karengkvnang* by the Kokoberra people and is the site of both catfish increase site and a nearby native bee increase site. The lagoon carries the name of *koy karengkvn* the catfish. Kokoberra Swamp is the potent site of the source of phlegmatic illness and in the centre of the wetland is Frilled Lizard Story that until the late 1970s was marked by a tree stump, now gone. Other wetlands are increase sites of poison snakes, native bee, Brown Crane and bamboo, a Phragmites increase site and Nail tailed wallaby creation story site. There are many more.

The most significant cultural value of water in a wetland landscape is that a comfortable site chosen for a departed family member's body spirit by grieving relatives is a place with a plentiful water supply, shade and shelter. Everyone avoids the place for a time to allow the body spirit to settle in peace. The essence of a person's birth is said to come from a water place. The ceremony of sending of a deceased's spirit is a significant cultural practice that continues into the present.

Association with Country: traditional activities

Significant places

Country is covered with named areas and sites and places of greater ceremonial activity now referred to as 'poison places.' These areas, due to the significance of historical ceremonies are covered by an array of restrictions. Some are areas with prohibited access. Others allow careful passage with certain restrictions on particular activities that include care against injury of any kind in the area, cutting, digging or plucking of plants, and, more particularly, no plant or animal foods are to be taken in the area. This unintentionally creates a nature preserve protecting areas of Country and regulating human activities such as infrastructural works, hunting activities and impacts upon the associated plants and animals. Culturally significant areas represent a very real ecosystem service to Country and the national estate enacted by its First People.

The presence of increase sites of the many species of plants and animals and phenomena such as rain and phlegmatic illness also govern permissible activities and recognise the relationship between humans and the environment. Traditional Owners were relieved when roads were rerouted away from the wetland sites of Poison Snake Story, *Minh themell* and Cough Story (Phlegmatic Illness), *PvnpeR wvtaR* in historical times. Currently, Rangers are working at Blue Tongued Lizard Story to ensure the continued integrity of that site. This has led to the restoration of the last remaining lotus bed (*Nelumbo nucifera*) on the lower Mitchell River delta, and the planting of a starter bed of water cane (*Phragmites australis*), that has been locally extinct for several decades due to predation by introduced grazing stock.

Trees of cultural significance

During the mission era (1905–1967) children were born at the mission. A legacy of mission days at Kowanyama is numerous sites where placental remains were buried and a tree was planted at the site. Those trees are now mostly large mature mango and other trees such as sandpaper fig (*Ficus opposita*), and the introduced trees cascara (*Cassia fistula*) and poinciana (*Delonix regia*). The trees are considered significant to individuals and families and now determine where new buildings are erected. Such is the attachment of humans to Country and cultural identity. The numerous mature aged mango trees are inhabited by native bees and brush tailed possums.

Sending of the spirit

Upon death the final ceremony before burial is the sending of the deceased's body spirit to a temporary resting place while other funeral ceremonies proceed through time. The spirit takes the form of a giant bat and resides at the designated place which has all the attributes of a good bush camp. Prerequisites are primarily water supply, shade and bark trees for shelter and cooking purposes. The site chosen is essentially a 'water place'. The area is avoided for a period of time, the duration of which is decided upon by kin. Occasionally closure can last longer than a year.

Closure and opening of Country

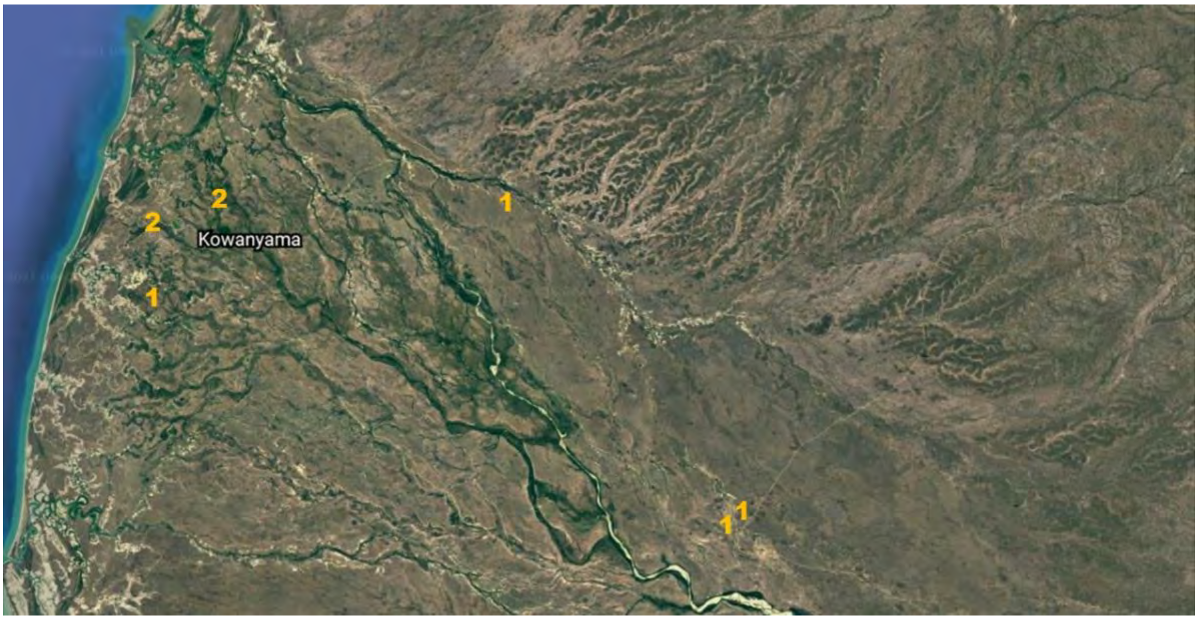
Upon death, the last places used by the deceased are inspected and any visible evidence is removed. Campfire ashes are scattered and any bush shelters are taken down by the appropriate kin. The area is then avoided along with other selected parts of the clan estate of the deceased to give peace and quiet, and a place of rest for the body spirit. This also gives Country around the physical space respite, albeit unintentionally, from human activities.

The closed Country is formally met and opened for use sometime later. Appropriate family members decide when an end is called to the restriction. Upon arrival at the closed area, ancestors are called upon, sometimes shots are fired, and the area is used for the first time since the death of the relative.

FigureC1: Distribution of body spirit sites indicating number sent 2018 to 2021. Number of individual sendings. Data collected by Viv Sinnamon using information from Indigenous Traditional Owners in Kowanyama and surrounding areas. Information and data presented in these maps remain the property of the Traditional Owners (or of their families in circumstances where they are deceased). Information and data from these maps must not be reproduced, nor should data be extracted and re-analysed in any way, without obtaining prior informed consent from the Traditional Owners through the Kowanyama Aboriginal Land and Natural Resource Management Office and Abm Elgoring Ambung RNTBC. Given the time constraints, a limited number of individuals and families were engaged in the provision of these data. This should not therefore be regarded as a comprehensive documentation of traditional land use.

Burial on Country

In recent decades, following the takeover of the Mitchell River Mission by the State and the establishment of an elected Aboriginal Council in 1987, there have been six burials on Country, at locations on a National Park and two neighbouring cattle properties as far as 70 km distant from Kowanyama. Five other bush burials were not possible due to the practicalities of wet season access.



FigureC2: Distribution of bush burials on Country. Number of burials indicated. Data collected by Viv Sinnamon using information from Indigenous Traditional Owners in Kowanyama and surrounding areas. Information and data presented in these maps remain the property of the Traditional Owners (or of their families in circumstances where they are deceased). Information and data from these maps must not be reproduced, nor should data be extracted and re-analysed in any way, without obtaining prior informed consent from the Traditional Owners through the Kowanyama Aboriginal Land and Natural Resource Management Office and Abm Elgoring Ambung RNTBC. Given the time constraints, a limited number of individuals and families were engaged in the provision of these data. This should not therefore be regarded as a comprehensive documentation of traditional land use.

To some this was a more tangible 'returning home' of the deceased and a strong reflection of the deceased and families' connection to their respective clan estates that are now on Country owned by others.

Customary restrictions upon the consumption of some bush foods

Traditionally a range of bush foods must not be eaten during bereavement and pregnancy. Only a brief description of indicative practices is provided here.

Certain kin of bereaved families are restricted in a range of foods, whether by species or location, e.g., coastal fish cannot be eaten by certain family members. Only freshwater fish can be eaten during that time until such time as the appropriate family members choose to lift the ban. In the case of pregnancy, both of the couple are under food restrictions during and following the pregnancy. That period in people's lives also determines the method of hunting and gathering of food resources.

Husbands must not kill birds by the wringing of necks but must kill them with sticks. Pregnant fathers are not to dig into the mounds of scrub fowl (*Megapodius reinwardt*), scrub turkey's (*Alectura lathami*) and saltwater crocodile (*Crocodilus porosis*) nests nor eat the eggs. The consumption of wallabies is restricted to mid-sized animals. Large bull and female wallabies and young wallabies cannot be eaten by the pregnant couple. A range of other species such as Echidna (*Tachyglossus aculeatus*) are also under similar prohibitions with a permanent prohibition on Emus (*Dromaius novaehollandiae*). Traditionally only the senior men of ceremony were permitted the consumption and use of emu products.

Breaking of these traditional restrictions has serious consequences for the health and wellbeing of both the unborn infant and parents. The mother and father are expected to take full responsibility for their prenatal actions, and those of others around them, with the potential to negatively affect the health and development of their child before and after birth.

Appendix D – Cross-walk between the Broad Vegetation Groups of Queensland and the IUCN Global Ecosystems Typology

Ecosystem types for the Mitchell catchment ecosystem accounting area were determined by cross-walking between the Broad Vegetation Groups of Queensland (Neldner et al. 2019) and the IUCN Global Ecosystems Typology (D. A. Keith et al. 2020), in consultation with experts at the Queensland Herbarium. The Version 4 spatial layer for the Broad Vegetation Groups of Queensland (Version 4, 2017) was used as the underlying ecosystem asset spatial layer for the Mitchell catchment. Version 5 Broad Vegetation Group mapping is now available; however this was released after the mapping for Project 4.6 had commenced.

There are 3 levels of broad vegetation groups, which reflect the approximate scale at which they are designed to be used (qld.gov.au/environment/plants-animals/plants/ecosystems/about#biodiversity):

- 1:5,000,000 (national)
- 1:2,000,000 (state)
- 1:1,000,000 (regional).

The matching was undertaken at the 1:1 Million level for the Broad Vegetation Groups (BGVs) and the Ecosystem Functional Group (EFG) level for the IUCN Global Ecosystem Typology (IUCN GET). EFGs are referred to as 'ecosystem types' in most project documentation.

TableD1: Cross-walk between the Broad Vegetation Groups of Queensland (Version 4, 2017) and the IUCN Global Ecosystem Typology for the Mitchell catchment.

Broad Vegetation Groups			IUCN Global Ecosystem Typology		
BVG at 1:2M	**BVG at 1:1M**	**Description**	**Biome**	**EFGs**	**Description**
10	10b	Moist open forests to woodlands dominated by Corymbia citriodora (spotted gum)	T4	T4.2	Pyric tussock savannas
11	11b	Moist to dry open forests to woodlands dominated by Eucalyptus crebra (narrow-leaved red ironbark) or E. tereticornis (blue gum), frequently with Corymbia species or E. microneura (Gilbert River box) on red ferrosols on undulating terrain	T4	T4.2	Pyric tussock savannas

TableD1 (continued).

Broad Vegetation Groups			IUCN Global Ecosystem Typology		
BVG at 1:2M	**BVG at 1:1M**	**Description**	**Biome**	**EFGs**	**Description**
11	11c	Moist woodlands dominated by Eucalyptus leptophleba (Molloy red box) ± Corymbia papuana (ghost gum) ± C. tessellaris (carbeen)	T4	T4.2	Pyric tussock savannas
12	12b	Woodlands and open woodlands dominated by Eucalyptus crebra (narrow-leaved red ironbark) and/or Corymbia spp. such as C. clarksoniana (grey bloodwood), C. stockeri, C. setosa (rough leaved bloodwood) or C. peltata (yellowjacket) on hilly terrain	T4	T4.2	Pyric tussock savannas
13	13a	Woodlands and open woodlands dominated by ironbarks such as Eucalyptus cullenii (Cullen's ironbark), E. staigeriana (lemon-scented ironbark) or E. melanophloia (silver-leaved ironbark) and bloodwoods such as Corymbia stockeri subsp. peninsularis, C. clarksoniana (grey bloodwood) or C. leichhardtii (rustyjacket)	T4	T4.2	Pyric tussock savannas
13	13b	Woodlands to open woodlands dominated by Eucalyptus microneura (Gilbert River box) on shallow soils on rolling hills	T4	T4.2	Pyric tussock savannas
13	13c	Woodlands of Eucalyptus crebra (narrow-leaved red ironbark), E. drepanophylla (grey ironbark), E. fibrosa (dusky-leaved ironbark), E. shirleyi (Shirley's silver-leaved ironbark) on granitic and metamorphic ranges	T4	T4.2	Pyric tussock savannas

TableD1 (continued).

Broad Vegetation Groups			IUCN Global Ecosystem Typology		
BVG at 1:2M	**BVG at 1:1M**	**Description**	**Biome**	**EFGs**	**Description**
14	14a	Woodlands and tall woodlands dominated by Eucalyptus tetrodonta (Darwin stringybark) (or E. megasepala), with Corymbia nesophila (Melville Island bloodwood). Occasionally E. chartaboma (or E. miniata (Darwin woollybutt)), on deeply weathered plateaus and remnants	T4	T4.2	Pyric tussock savannas
14	14b	Woodlands dominated by Eucalyptus tetrodonta (Darwin stringybark) (or E. megasepala) or E. chartaboma or E. miniata (Darwin woollybutt), with Corymbia clarksoniana (grey bloodwood) on erosional surfaces, residual sands and occasionally alluvial plains	T4	T4.2	Pyric tussock savannas
14	14d	Woodlands dominated by Corymbia stockeri (or C. hylandii) and Eucalyptus megasepala (or E. tetrodonta (Darwin stringybark)) on sandstone, metamorphic and ironstone ranges	T4	T4.2	Pyric tussock savannas
16	16a	Open forests and woodlands dominated by Eucalyptus camaldulensis (river red gum) (or E. tereticornis (blue gum)) and/or E. coolabah (coolibah) (or E. microtheca (coolabah)) fringing drainage lines. Associated species may include Melaleuca spp., Corymbia tessellaris (carbeen), Angophora spp., Casuarina cunninghamiana (river she-oak). Does not include alluvial areas dominated by herblands or grasslands or alluvial plains that are not flooded	TF1	TF1.2	Subtropical-temperate forested wetlands

TableD1 (continued).

Broad Vegetation Groups			IUCN Global Ecosystem Typology		
BVG at 1:2M	**BVG at 1:1M**	**Description**	**Biome**	**EFGs**	**Description**
16	16b	Woodlands dominated by Eucalyptus leptophleba (Molloy red box), and associated Corymbia tessellaris (carbeen) or C. clarksoniana (grey bloodwood) or C. dallachiana; or dominated by Corymbia terminalis (desert bloodwood) or other Corymbia spp. in the Gulf Plains and Northwest Highlands bioregions. On sandy levees	T4	T4.2	Pyric tussock savannas
16	16c	Woodlands and open woodlands dominated by Eucalyptus coolabah (coolibah) or E. microtheca (coolibah) or E. largiflorens (black box) or E. tereticornis (blue gum) or E. chlorophylla on floodplains. Does not include alluvial areas dominated by herblands or grasslands or alluvial plains that are not flooded	TF1	TF1.2	Subtropical-temperate forested wetlands
16	16d	River beds, open water or sand, or rock, frequently not vegetated	TF1	TF1.2	Subtropical-temperate forested wetlands
17	17b	Woodlands to open woodlands dominated by Eucalyptus melanophloia (silver-leaved ironbark) (or E. shirleyi (Shirley's silver-leaved ironbark)) on sand plains and footslopes of hills and ranges	T4	T4.2	Pyric tussock savannas

TableD1 (continued).

Broad Vegetation Groups			IUCN Global Ecosystem Typology		
BVG at 1:2M	**BVG at 1:1M**	**Description**	**Biome**	**EFGs**	**Description**
18	18a	Dry woodlands to open woodlands, dominated by bloodwoods (Corymbia dallachiana, C. terminalis (western bloodwood), C. plena, or C. leichhardtii (rustyjacket)) or ironbarks (Eucalyptus quadricostata (Pentland ironbark), E. crebra (narrow-leaved red ironbark) or E. exilipes (fine-leaved ironbark)), often with E. acmenoides (narrow-leaved white stringybark), Angophora leiocarpa (rusty gum) and Callitris glaucophylla (white cypress pine) in the Brigalow Belt, on sandy plateaus and plains	T4	T4.2	Pyric tussock savannas
18	18b	Woodlands dominated Eucalyptus crebra (narrow-leaved red ironbark) frequently with Corymbia spp. or Callitris spp. on flat to undulating plains	T4	T4.2	Pyric tussock savannas
18	18c	Woodlands and open woodlands dominated by Eucalyptus chlorophylla (or E. leptophleba (Molloy red box) on heavy soils) frequently with Corymbia spp.; or dominated by E. tectifica west of Burketown	T4	T4.2	Pyric tussock savannas
18	18d	Woodlands to low open woodlands dominated by Eucalyptus microneura (Gilbert River box/Georgetown box) sometimes with Corymbia spp.	T4	T4.2	Pyric tussock savannas
19	19d	Low open woodlands dominated by Eucalyptus persistens (or E. normantonensis (Normanton box), E. tardecidens, E. provecta) with Triodia spp. dominated ground layer, mainly on hills and ranges	T4	T4.3	Hummock savannas

TableD1 (continued).

Broad Vegetation Groups			IUCN Global Ecosystem Typology		
BVG at 1:2M	**BVG at 1:1M**	**Description**	**Biome**	**EFGs**	**Description**
1	1a	Complex mesophyll to notophyll vine forests usually in fertile and very wet locations	T1	T1.1	Tropical-subtropical lowland rainforests
20	20a	Woodlands to open forests dominated by Callitris glaucophylla (white cypress pine) or C. intratropica (northern cypress pine)	T4	T4.4	Temperate woodlands
21	21a	Low woodlands and low open woodlands dominated by Melaleuca viridiflora (coarse-leaved paperbark) on depositional plains	T4	T4.2	Pyric tussock savannas
21	21b	Low open woodlands and tall shrublands of Melaleuca citrolens or M. stenostachya or other Melaleuca spp.	T4	T4.2	Pyric tussock savannas
22	22a	Open forests and woodlands dominated by Melaleuca quinquenervia (swamp paperbark) in seasonally inundated lowland coastal areas and swamps	TF1	TF1.2	Subtropical-temperate forested wetlands
22	22b	Open forests and low open forests dominated by Melaleuca spp. (M. viridiflora, M. saligna, M. leucadendra (broad-leaved tea-tree), M. clarksonii or M. arcana (winti)) in seasonally inundated swamps	TF1	TF1.2	Subtropical-temperate forested wetlands
22	22c	Open forests dominated by Melaleuca spp. (M. argentea (silver tea-tree), M. leucadendra (broad-leaved tea-tree), M. dealbata (swamp tea-tree) or M. fluviatilis), fringing major streams with Melaleuca saligna or M. bracteata (black tea-tree) in minor streams	TF1	TF1.2	Subtropical-temperate forested wetlands

TableD1 (continued).

Broad Vegetation Groups			IUCN Global Ecosystem Typology		
BVG at 1:2M	**BVG at 1:1M**	**Description**	**Biome**	**EFGs**	**Description**
24	24a	Low woodlands to tall shrublands dominated by Acacia spp. on residuals. Species include A. shirleyi (lancewood), A. catenulata (bendee), A. microsperma (bowyakka), A. clivicola, A. sibirica (bastard mulga), A. rhodoxylon (rosewood) and A. leptostachya (Townsville wattle)	T4	T4.3	Hummock savannas
27	27c	Low open woodlands dominated by a variety of species including Grevillea striata (beefwood), Acacia spp., Terminalia spp. or Cochlospermum spp.	T3	T3.1	Seasonally dry tropical shrublands
28	28a	Complex of open shrublands to closed shrublands, grasslands, low woodlands and open forests, on strand and foredunes. Includes pure stands of Casuarina equisetifolia (coastal she-oak)	MT2	MT2.1	Coastal shrublands and grasslands
28	28b	Open forests to woodlands dominated by Acacia crassicarpa (brown salwood) or other Acacia spp. with Syzygium spp., Corymbia spp. and/or Parinari nonda (parinari)	MT2	MT2.1	Coastal shrublands and grasslands
28	28c	Low open forests dominated by Asteromyrtus brassii, Neofabricia myrtifolia, Allocasuarina littoralis (woolly oak), Melaleuca viridiflora (coarse-leaved paperbark) on sandplains and plateaus; or Acacia brassii low open forests or Melaleuca viridiflora low woodlands on ranges; or Thryptomene oligandra ± Neofabricia mjoebergii ± Melaleuca viridiflora woodlands on drainage depressions	T3	T3.1	Seasonally dry tropical shrublands

TableD1 (continued).

Broad Vegetation Groups			IUCN Global Ecosystem Typology		
BVG at 1:2M	**BVG at 1:1M**	**Description**	**Biome**	**EFGs**	**Description**
28	28e	Low open forests to woodlands dominated by Lophostemon suaveolens (swamp box) (or L. confertus (brush box)) or Syncarpia glomulifera (turpentine) frequently with Allocasuarina spp. on rocky hill slopes	T4	T4.2	Pyric tussock savannas
29	29b	Open shrublands to open heaths on elevated rocky substrates	T3	T3.1	Seasonally dry tropical shrublands
2	2a	Complex evergreen notophyll vine forests frequently with Araucaria cunninghamii from foothills to ranges.	T1	T1.3	Tropical-subtropical montane rainforests
30	30a	Tussock grasslands dominated by Astrebla spp. (Mitchell grass) or Dichanthium spp. (bluegrass) often with Eulalia aurea (silky browntop) on alluvia	T4	T4.2	Pyric tussock savannas
30	30b	Tussock grasslands dominated by Astrebla spp. (Mitchell grass) or Dichanthium spp. (bluegrass) often with Iseilema spp. on undulating downs or clay plains	T4	T4.2	Pyric tussock savannas
31	31a	Open forblands to open tussock grasslands which may be composed of Atriplex spp. (saltbush), Sclerolaena spp. (burr), Asteraceae spp. and/or short grasses on alluvial plains	T5	T5.1	Semi-desert steppes
32	32a	Closed tussock grasslands dominated by Eriachne spp., Fimbristylis spp., Aristida spp. or Panicum spp.; or Themeda arguens, Dichanthium sericeum (Queensland bluegrass) or Imperata cylindrica (blady grass) on marine and alluvial plains	T4	T4.2	Pyric tussock savannas

TableD1 (continued).

Broad Vegetation Groups			IUCN Global Ecosystem Typology		
BVG at 1:2M	**BVG at 1:1M**	**Description**	**Biome**	**EFGs**	**Description**
32	32b	Closed tussock grasslands and associated open woodlands on undulating clay plains, upland areas and headlands. Dominant species include Heteropogon triticeus (giant speargrass) or Themeda arguens or Sarga plumosum or Imperata cylindrica (blady grass) or Mnesithea rottboellioides (cane grass)/Arundinella setosa. With areas of open woodland dominated by tree species such as Corymbia papuana (ghost gum)/Terminalia spp./Vachellia ditricha/Piliostigma malabaricum	T4	T4.2	Pyric tussock savannas
33	33b	Hummock grasslands dominated by Triodia pungens or T. longiceps (giant grey spinifex) or T. mitchellii (buck spinifex) sandplains or lateritic surfaces	T4	T4.3	Hummock savannas
34	34a	Lacustrine wetlands. Lakes, ephemeral to permanent, fresh to brackish; water bodies with ground water connectivity. Includes fringing woodlands and sedgelands	TF1	TF1.4	Seasonal floodplain marshes
34	34c	Palustrine wetlands. Freshwater swamps on coastal floodplains dominated by sedges and grasses such as Oryza spp., Eleocharis spp. (spikerush) or Baloskion spp. (cord rush)/Leptocarpus tenax/Gahnia sieberiana (sword grass)/Lepironia spp. Includes small areas of estuarine wetlands	TF1	TF1.4	Seasonal floodplain marshes
34	34d	Palustrine wetlands. Freshwater swamps or billabongs on floodplains ranging from permanent and semi-permanent to ephemeral	TF1	TF1.4	Seasonal floodplain marshes

TableD1 (continued).

Broad Vegetation Groups			IUCN Global Ecosystem Typology		
BVG at 1:2M	**BVG at 1:1M**	**Description**	**Biome**	**EFGs**	**Description**
34	34e	Palustrine wetlands. Springs with water dependent herbs	TF1	TF1.4	Seasonal floodplain marshes
34	34f	Palustrine wetlands. Sedgelands/grasslands on seeps and soaks on wet peaks, and other coastal non-floodplain features	TF1	TF1.4	Seasonal floodplain marshes
35	35a	Closed forests and low closed forests dominated by mangroves	MFT	MFT1.2	Intertidal forests and shrublands
35	35b	Bare saltpans ± areas of Tecticornia spp. (samphire) sparse forblands and/or Xerochloa imberbis or Sporobolus virginicus (sand couch) tussock grasslands	MFT	MFT1.3	Coastal saltmarshes and reedbeds
3	3a	Evergreen to semi-deciduous, notophyll to microphyll vine forests/ thickets on beach ridges and coastal dunes, occasionally Araucaria cunninghamii (hoop pine) microphyll vine forests on dunes. Pisonia grandis on coral cays	T1	T1.1	Tropical-subtropical lowland rainforests
4	4a	Notophyll and mesophyll vine forests with feather or fan palms in alluvia and in swampy situations on ranges or within coastal sand masses	T1	T1.1	Tropical-subtropical lowland rainforests
4	4b	Evergreen to semi-deciduous mesophyll to notophyll vine forests, frequently with Archontophoenix spp., fringing streams	T1	T1.1	Tropical-subtropical lowland rainforests
5	5c	Simple to complex notophyll vine forests, often with Agathis spp. on ranges and uplands of the Wet Tropics bioregion	T1	T1.3	Tropical-subtropical montane rainforests

TableD1 (continued).

Broad Vegetation Groups			IUCN Global Ecosystem Typology		
BVG at 1:2M	**BVG at 1:1M**	**Description**	**Biome**	**EFGs**	**Description**
5	5d	Acacia celsa/A. mangium (brown sandalwood)/A. polystachya closed forests to open forests with mixed rainforest species understorey includes areas regenerating after disturbance (upland and lowland areas)	T1	T1.2	Tropical-subtropical dry forests and scrubs
6	6b	Simple evergreen notophyll vine forests to simple microphyll vine fern thickets on high peaks and plateaus of northern Queensland	T1	T1.3	Tropical-subtropical montane rainforests
7	7a	Semi-evergreen vine thickets on wide range of substrates	T1	T1.2	Tropical-subtropical dry forests and scrubs
7	7b	Deciduous microphyll vine thickets on ranges and heavy clay alluvia in northern bioregions	T1	T1.2	Tropical-subtropical dry forests and scrubs
8	8a	Wet tall open forests dominated by species such as Eucalyptus grandis (flooded gum) or E. saligna, E. resinifera (red mahogany), Lophostemon confertus (brush box), Syncarpia spp. (turpentine), E. laevopinea (silvertop stringybark)	T4	T4.2	Pyric tussock savannas
9	9b	Moist to dry woodlands dominated by Eucalyptus platyphylla (poplar gum) and/or E. leptophleba (Molloy red box). Other frequent tree species include Corymbia clarksoniana (grey bloodwood), E. drepanophylla (grey ironbark) and occasionally E. chlorophylla	T4	T4.2	Pyric tussock savannas

TableD1 (continued).

Broad Vegetation Groups			IUCN Global Ecosystem Typology		
BVG at 1:2M	**BVG at 1:1M**	**Description**	**Biome**	**EFGs**	**Description**
9	9c	Open forests of Corymbia clarksoniana (grey bloodwood) (or C. intermedia (pink bloodwood) or C. novoguinensis), C. tessellaris (carbeen) ± Eucalyptus tereticornis (blue gum) predominantly on coastal ranges. Other frequent tree species include Eucalyptus drepanophylla (grey ironbark), E. pellita (large-fruited red mahogany), E. brassiana (Cape York red gum) and Lophostemon suaveolens (swamp box)	T4	T4.2	Pyric tussock savannas
9	9d	Moist to dry open forests to woodlands dominated by Eucalyptus portuensis, Corymbia intermedia (pink bloodwood), E. drepanophylla, E. resinifera or E. reducta +/-Syncarpia glomulifera (turpentine) or E. cloeziana (Gympie messmate) on ranges. Also includes mixed forests with E. pellita or C. torelliana (cadaghi) emergents and rainforest understories	T4	T4.2	Pyric tussock savannas
9	9e	Open forests, woodlands and open woodlands dominated by Corymbia clarksoniana (grey bloodwood) (or C. novoguinensis or C. intermedia (pink bloodwood) or C. polycarpa (long-fruited bloodwood)) frequently with Erythrophleum chlorostachys (red ironwood) or Eucalyptus platyphylla (poplar gum) predominantly on coastal sandplains and alluvia	T4	T4.2	Pyric tussock savannas

Appendix E – Definitions of remnant and non-remnant vegetation in the Broad Vegetation Groups of Queensland

The information contained in this appendix is summarised from a Queensland Department of Science, Information Technology and Innovation Report conducted as part of the Statewide Landcover and Trees Study (SLATS) that detailed land cover change in Queensland 2015-16 (Queensland Government (Department of Science Information Technology and Innovation), 2017).

SLATS is an initiative of the Queensland Government to monitor vegetation extent (and therefore vegetation loss) attributable to human activities, via a combination of automated and manual mapping techniques, across the State. The mapping is based on Landsat satellite imagery and supported by other data sources. SLATS was established to support regulation and monitoring of native vegetation clearing under the Vegetation Management Act 1999.

The Vegetation Management Act 1999 provides the following definition of *remnant vegetation*:

'vegetation –

- (a) that is –
  - i. an endangered regional ecosystem; or
  - ii. an of concern regional ecosystem; or
  - iii. a least concern regional ecosystem; and
- (b) forming the predominant canopy of the vegetation –
  - i. covering more than 50% of the undisturbed predominant canopy; and
  - ii. averaging more than 70% of vegetation's undisturbed height; and
  - iii. composed of species characteristics of the vegetation's undisturbed predominant canopy.'

(Vegetation Management Act 1999[75] p138-139).

Remnant vegetation includes all broad vegetation groups (BVGs) defined in Neldner et al. (2019) using floristic, structural, functional, biogeographic and ladnscape attributes. Remnant vegetation includes woody vegetation (rainforests, eucalypt forests, trees and tall shrubs that are not aucalypts or rainforest species), non-woody vegetation (e.g., hummock grasslands and other remnant areas (e.g., freshwater wetlands, intertidal areas) (DSITI 2017, Neldner et al 2019). *Non-remant vegetation* including regrowth, is defined as any vegetation that does not fall within the Vegetation Management Act 1999 defintion for remnant vegetation (Queensland Government (Department of Science Information Technology and Innovation), 2017).

[75] Vegetation Management Act 1999 Current as at 3 July 2017—revised version, available at: legislation.qld.gov.au/view/pdf/2017-07-03/act-1999-090, date accessed 19 Sept 2021.

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