Australian Government

Department of Climate Change, Energy, the Environment and Water

Accounting for the benefits from coastal restoration: A case study from the Hunter River

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Cover and back cover image by Chris McCormack, Remember the Wild

Acknowledgement of Country

We acknowledge the Traditional Custodians of Australia and their continuing connection to land and sea, waters, environment and community. We pay our respects to the Traditional Custodians of the lands we live and work on, their culture, and their Elders past and present.

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Executive Summary

This report was prepared for the Commonwealth Department of Climate Change, Energy, the Environment and Water (DCCEEW) by a consortium led by Deakin University as part of a project to develop a Guide to Measuring and Accounting for the Benefits of Restoring Coastal Blue Carbon Ecosystems – Version 1 (hereafter “the Guide”).

This case study demonstrates how restoration of blue carbon ecosystems can benefit society by implementing the Guide, testing the proposed processes and methods in a real-world example of a blue carbon ecosystem restoration project. It provides a practical case study for potential users of the Guide. Since this case study was developed using existing data, rather than planned using the methods outlined in the Guide, in some instances the approaches detailed in the Guide had to be adapted to take this into account. This case study also includes a *General discussion and lessons learned* section and information on the author’s *Reflections relative to the Guide*. These sections represent the authors’ experience in developing and applying the Guide and case studies.

Here the case study measures the impacts of a restoration project in the Tomago Wetland on the Hunter River in Newcastle, New South Wales. This site has significant environmental value but has been heavily modified by levees, floodgates and culverts to increase land available to industry and agriculture. The restoration project aimed to increase the extent of saltmarsh and reduce the extent of pasture with the managed restoration of tidal flushing through installation of water gates, control of invasive species and construction of low levees.

As outlined in the Guide, the process used to document the impacts of restoration at the site was designed around the System of Environmental Economic Accounting Ecosystem Accounting (SEEA–EA) framework. The SEEA-EA employs a rigorous approach to building accounts that can be used to inform decision-making by tracking changes in ecosystem extent and condition as well as changes to the physical and monetary ecosystem services produced on the site following restoration.

This case study details the application of methodologies to assess changes that restoration activities have produced in the Tomago Wetland restoration area, in relation to:

- Ecosystem extent and condition, particularly in relation to saltmarsh, and supratidal forests.
- Ecosystem services, including carbon sequestration and emissions, water purification, coastal protection, fish nursery and biomass provisioning, and recreational services such as fishing and birdwatching.

Two sets of accounts were prepared for each of the above, one representing ‘before restoration’ (2007) and one representing the outputs of the restoration site in 2021.

Results

Some key biophysical results of the restoration project are presented in **Table ES.1**. The restoration project produced an increase in the extent of blue carbon ecosystems, particularly saltmarsh and supratidal forest. These areas have expanded by replacing other land covers, mostly pasture.

The most significant changes in condition were for the target ecosystem for restoration, saltmarsh, for which there was a net decline in vegetation cover (19 ha improved and 65 ha decline) and vegetation greenness (29 ha improved and 54 ha declined). The Supratidal forests ecosystem increased in net area, and improved in cover (18 ha improved and 1 ha declined), vegetation greenness (18 ha improved and 1 ha declined) and landscape wetness (19 ha improved).

Following changes in ecosystem extent and condition, carbon abatement and stock estimates also changed. Estimates were calculated using a nationally consistent approach, a detailed approach (using BlueCAM), and a detailed approach with site specific data (also using BlueCAM). Carbon abatement and stock estimates using the detailed and site-specific detail approaches were ~30 % and ~100 % higher respectively.

Table ES.2 presents a range of ecosystem service impacts of the restoration project. These include: estimates for additional fishing and bird watching trips produced from restoration and their economic value; increases in fish biomass and their estimated impact on commercial fisheries along with the economic value of this change; carbon abatement through avoided emissions from changes in land cover; and sequestration in vegetation and soil over the analysis period.

Table ES.1: Ecosystem extent and condition changes from the Hunter Restoration Project

	Aspect measured	Change attributable to the project
Ecosystem extent[1]	Total area blue carbon ecosystems	Increase of 45.9 ha or 198.1 ha*
	Saltmarsh	Increase of 35.5 ha or 140 ha*
	Supratidal forest	Increase of 10.4 ha or 58.3 ha*
	Waterbodies/mudflats	Increase of 45.1 ha or 0.62 ha*
	Other land covers	Decrease of -91 ha or -261 ha*
Ecosystem condition	Saltmarsh – Vegetation cover	Increasing: 19 ha; Decreasing: 65 ha; Net: -46 ha
	Saltmarsh – Above-ground biomass	Increasing: 51 ha; Decreasing: 32 ha; Net: +19 ha
	Saltmarsh – Vegetation greenness	Increasing: 29 ha; Decreasing: 54 ha; Net: -25 ha
	Saltmarsh – Landscape wetness	Increasing: 53 ha; Decreasing: 31 ha; Net +22 ha
	Saltmarsh - Connectivity	Marginal increase (0.03 index points)
	STF[2] – Vegetation cover	Increasing: 18 ha; Decreasing: 1 ha; Net: +17 ha
	STF – Above-ground biomass	Increasing: 10 ha; Decreasing: 9 ha; Net: +1 ha
	STF – Vegetation greenness	Increasing: 18 ha; Decreasing: 1 ha; Net: +17 ha
	STF – Landscape wetness	Increasing: 19 ha; Decreasing: 0 ha; Net +19 ha
	STF - Connectivity	Marginal increase (0.05 index points)

**Calculations from using the nationally consistent approach or detailed approach*

[1] Ranges represent different estimation methodologies used.

[2] STF = Supratidal forests.

Table ES.2: Key estimated ecosystem service change from 2007 to 2022 (and selected other impacts), estimated increase in existence value, and actions and costs. All estimates were made using the detailed extent approach.

Component	Aspect measured	Change attributable to the project (2022 data unless stated otherwise)	$AUD ($2022 unless otherwise stated)
Cultural services - recreation	Recreational fishing	299 fishing trips per year	$36,215 per year ($93,298 welfare value)
	Recreational bird watching	204 birdwatching trips per year	$20,076 per year ($35,641 welfare value)
Fish nursery provisioning service	Fish biomass	4,513.5 kg per year	Not applicable
Fish biomass provisioning service	Commercial fishery species biomass	21,460 kg per year	$61,692 per year
Carbon abatement	Emissions avoided	-2,916 t CO_2e -7,376 t CO_2e over analysis period*	-$89,671 - -$1,106,135 over analysis period (2007-2022)*
	Carbon sequestered in vegetation and soil	10,273 t CO_2e - 22,176 t CO_2e over analysis period*	$315,895 - $3,326,409 over analysis period (2007-2022)*
	Net abatement amount [avoided emissions + carbon sequestration]	7,357 t CO_2e – 14,800 t CO_2e over analysis period*	$226,225 - $2,220,058 over analysis period (2007-2022)*
Existence value	Community existence value for restoration	Value of community preferences for wetland restoration	$18,619 per year (welfare value)
Restoration costs	Total cost of restoration over project period	Tidal gate modification and removal, 1.2km of additional levee, maintenance and monitoring, pest management	$4,105,559 in combined expenditures over analysis period

**Calculations from using the nationally consistent approach or detailed approach, the detailed approach provided higher apparent benefits than the national approach*

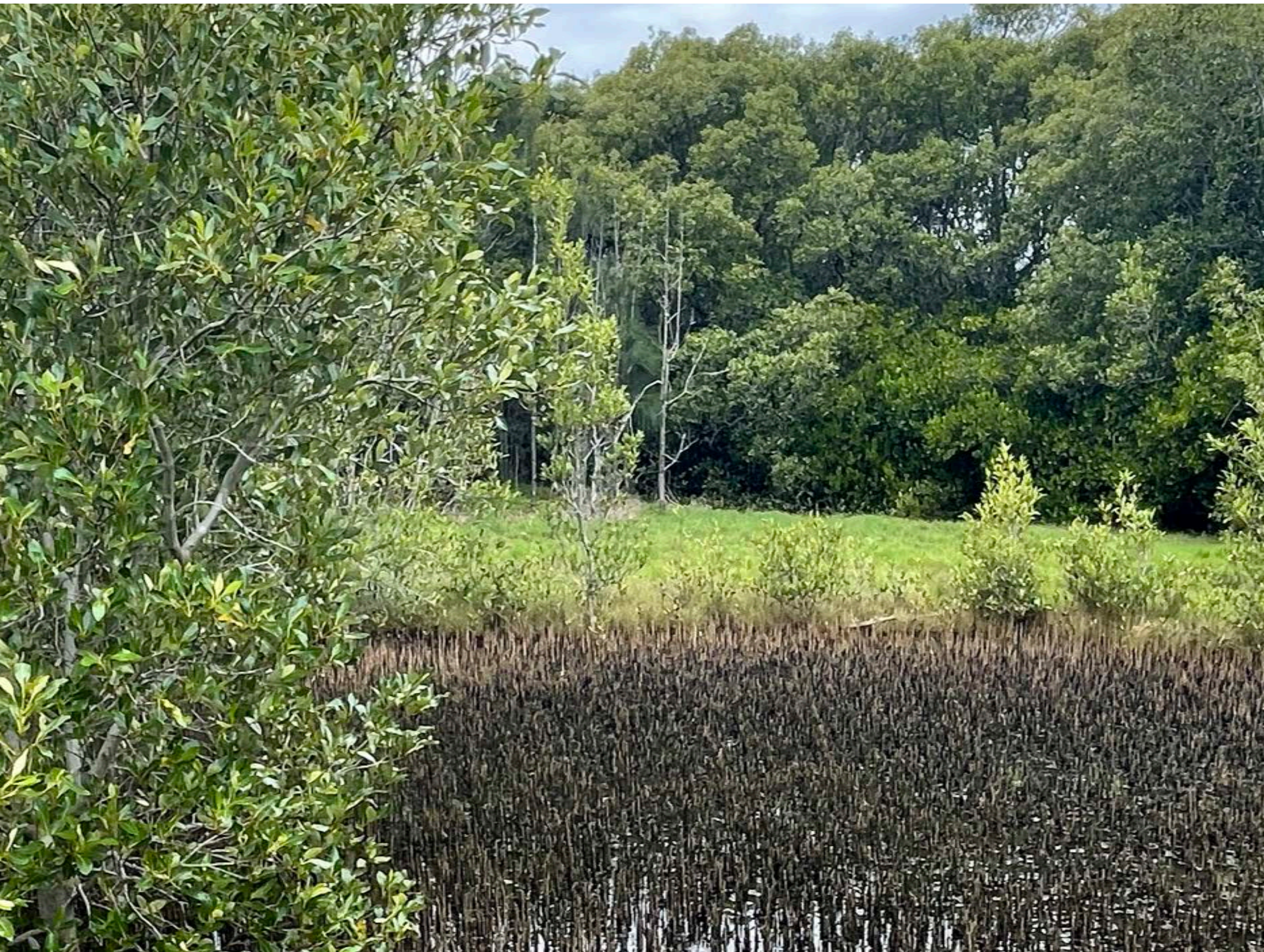
Reflections

As a restoration site well known and studied by the project team, the site has a high level of data availability, allowing the project team to trial different methodologies for accounting for change, and these insights have fed back into the Guide.

Perhaps the most conceptually challenging aspect of measurement in this case study has been estimating ecosystem condition changes, since the case study was backwards-looking we could only use existing data. A clear and defensible set of condition indicators will be needed by project proponents at the start of a project to ensure the integrity of restoration actions over time. While many aspects of condition can be estimated, it is challenging to define and then measure a limited set of indicators that appropriately encompass the relevant changes that a restoration project produces, particularly as some changes will inevitably be unpredictable. This has been exacerbated in this case study as we were reliant on existing data, thus requiring data inputs that were available in 2007, before project commencement. This issue will not be relevant for users of the Guide who establish and collect the appropriate condition data in accordance with the Guide, both Before and After restoration activities have commended.

Regarding how well the SEEA-EA framework performs as a reporting method, we found it has clear and repeatable logic that should be able to accommodate most of the types of impacts that a restoration project can produce.

Please see **Section 6** for more detailed reflections and lessons learnt.



1. Introduction

1.1 Introduction to this report

The ability to measure the impacts of restoration projects in Blue Carbon ecosystems is critical to demonstrating the benefits that restoration projects produce. With that in mind, the report '*A Guide to Measuring and Accounting for the Benefits of Restoring Coastal Blue Carbon Ecosystems*' has been developed to recommend and describe a process and methodologies to measure the main ecosystem services these ecosystems can provide, including the value provided to commercial fisheries, recreational activities, carbon sequestration, and coastal protection.

The Guide outlines recommended methods that should be used to establish a baseline, monitor and report on the benefits of restoration projects in Blue Carbon ecosystems. To test this guidance and demonstrate how it can be used in practice, the process and methodologies outlined in the Guide have been applied to two case study areas. This report outlines its application to the Tomago Wetland blue carbon ecosystem in New South Wales, Australia.

1.2 Tomago Wetland, Hunter River

The Hunter River is a mature barrier estuary[3] that runs through Newcastle, NSW, Australia, and supports large amounts of temperate estuarine wetlands that include saltmarsh and mangroves. Many of the wetlands within this system are Ramsar protected because of their frequent use by migrating birds. As a result of its extent and proximity (10 km) to the port of Newcastle however, these wetlands have been heavily modified by levees, floodgates, and culverts to increase land available to industry and agriculture. Tomago Wetland is a protected area within this system ~450 ha in size on the north end of the north channel of the Hunter River. This wetland is adjacent to Fullerton Cove which, together with the north arm of the Hunter River, is where most of the commercial fishery activity occurs within the Hunter River.

Tomago Wetland has been identified as critical habitat for migratory bird species[4], as well as resident species that roost, feed and reproduce within these areas[5]. As a result of its importance for migratory birds, and a history of human modification, Tomago Wetland was identified as an ideal site for restoration activities.

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[3] Roy, P. S., et al. "Structure and function of south-east Australian estuaries." *Estuarine, coastal and shelf science* 53(3) (2001), 351-384. https://doi.org/10.1006/ecss.2001.0796

[4] Saintilan, N., et al. "Climate change impacts on the coastal wetlands of Australia." *Wetlands* 39 (2019), 1145-1154. https://doi.org/10.1007/s13157-018-1016-7

[5] Lindsey, A. "The birds of Tomago Wetland after reinstatement of tidal flushing." *The Whistler* 15 (2021), 6-26.

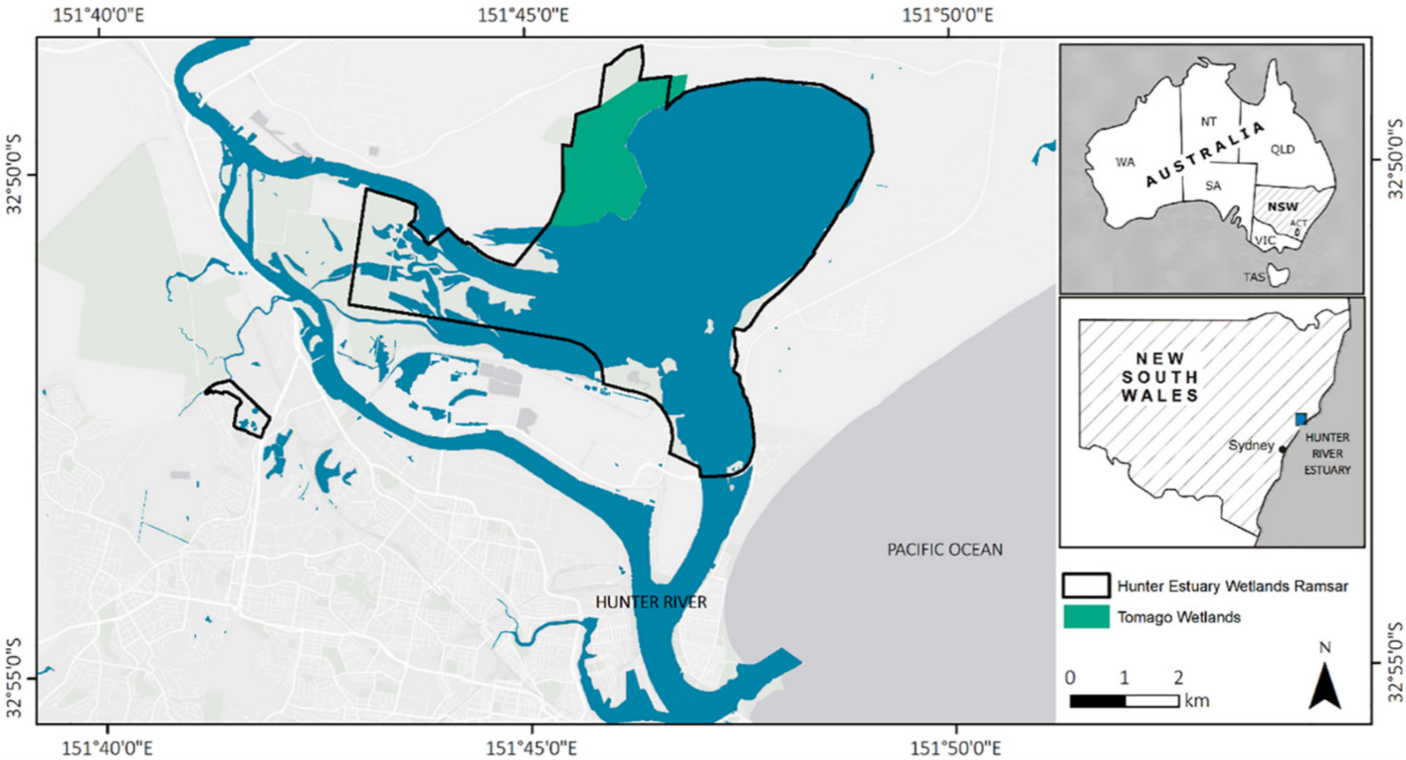

Figure 1.1: Map of Tomago Wetland restoration site (in green) in relation to the Hunter River. Adapted from Glamore et al. 2021[6] under Creative Commons.

1.3 History prior to restoration

Modifications to the Tomago wetlands largely occurred between 1913 and 1928, when a levee and internal drainage system was constructed around the perimeter of the site. The drainage system was then enlarged further between 1968 and 1980. These engineering works, including the installation of floodgates, excluded tidal waters from Tomago Wetlands and forced the site to only drain and not re-fill. The reason for these modifications was to limit flooding for the lower Hunter River estuary. During non-flood periods, dry-land agriculture was promoted but has subsequently failed[7].

Drainage and the exclusion of tidal waters within the study site degraded the existing coastal saltmarsh habitat and fostered the growth of non-saltmarsh species[8]. Coastal saltmarsh plants then progressively disappeared and were replaced by the freshwater pasture species, *Paspalum dilatatum*. The cumulative result of the drainage included lowering the water table, which oxidised sub-surface acid sulphate soils causing soil acidification and poor water quality runoff (pH<4). A review of the extent of saltmarsh habitats across the broader Hunter Wetlands National Park (which includes the Tomago wetland) concluded that, since the area had been modified, there had been a 41 % decrease in coastal saltmarsh from 827 ha to 339 ha across the park. These measured declines were beyond the "Limits of Acceptable Change" set for a Ramsar listed wetland, such as Tomago, and subsequently management action (restoration) was required.

[6] Glamore, W., Rayner, D., Ruprecht, J., Sadat-Noori, M., & Khojasteh, D. (2021). Eco-hydrology as a driver for tidal restoration: Observations from a Ramsar wetland in eastern Australia. PlosOne, 16(8), https://doi.org/10.1371/journal.pone.0254701

[7] Rayner, D. & Glamore, W. (2010). Tidal inundation and wetland restoration of Tomago wetland: Hydrodynamic modelling. UNSW Water Research Laboratory—Technical Report, Sydney. https://10.13140/RG.2.2.35070.92488

[8] Rayner, D., Glamore, W., Grandquist, L., Ruprecht, J., Waddington, K., & Khojasteh, D. (2012). Intertidal wetland vegetation dynamics under rising sea levels. Science of the Total Environment, 776, 144237. pmid:33421788

1.4 Restoration project description

Restoration was undertaken using a staged approach, with the overall objective of increasing the extent of saltmarsh and reducing the extent of pasture. The three stages of restoration were implemented over an 8-year period. Stage 1 opened in November 2007, Stage 2 in September 2011, and Stage 3 in December 2015 (**Figure 1.2**). The restoration strategy and scenario testing were designed such that all stages of restoration were considered to ensure optimal inundation hydroperiods across the site to target saltmarsh species.

Stage 1 of the restoration involved the construction and installation of electronic SmartGates[9] to enable accurate wetland water level control, clearing of in-drain freshwater weed vegetation species to promote efficient tidal flushing, isolation of the Stage 1 area by installing one-way floodgates on internal drain culvert structures, and construction of low levees to limit the impact of tidal flushing on adjacent private land holders. Removal of exotic vegetation and mangroves was also undertaken immediately prior to tidal restoration. Water levels and salinities in adjacent land and connected waterways were monitored to ensure impacts to adjacent landholders were minimised.

Following the restoration of tidal flushing, water levels, water quality, fisheries, and wetland vegetation responses were routinely monitored across the Stage 1 restoration area. Based on the monitoring, tidal flushing of Stage 2 was restored via the installation of buoyancy controlled SwingGates (**Figure 1.3**). The SwingGates were

Project Timeline

2006-2007

Stage 1 restoration area - ‘proof of concept’ trials used to assess primary tidal restoration objectives of the site

- Numerical modelling completed to predict changes in hydrodynamics and inundation
- Modifiications to four of the five site’s western culverts to include automated SmartGates (location 1) controlled using downstream water levels
- Installation of new one-way flaps on culverts to precent tidal inundation of upstream properties (location 6), and construction of 1.2 km levee on the north-west boundary

2008-2009

Monitoring - monitoring equipment installed to improve the understanding of the impacts of the restoration and to help guide further restoration

- Site monitoring including elevated telemetered camera, water levels, culvert discharges, and vegetation quadrant

2010-2011

Stage 2 restoration area - partial opening of eastern portion of site to tidal exchange and floodplain inundation

- Further numerical modelling to guide the implementation of Stage 2
- Modifications to site’s eastern culverts (location 8) to include buoyancy controlled SwingGates at all four floodgates
- Installation of one-way flaps (location 9) to prevent tidal inundation of Stage 3 area
- Reconnection of relic drain to the main ring drain (location 13) with rock weir

2012-2015

Stage 3 restoration area - opening of far eastern component of site to tidal exchange and floodplain inundation

- Final round of numerical modelling of Stage 3 actions
- Installation of new one-way floodgates on north-eastern corner of the property to prevent tidal inundation of upstream properties (location 11). Separate to the restoration area, an additional property was purchased to the east of the wetland
- Modification of flap gates on eastern ring drain (location 9) to include sluice gates allowing tidal exchange to Stage 3 area
- Removal of one-way floodgate from floodgate on the western side of the north-south drain (location 5)

Figure 1.2: Timeline of restoration works at Tomago Wetlands.

[9] Glamore, W. “Incorporating innovative engineering solutions into tidal restoration studies.” T*idal Marsh Restoration: A Synthesis of Science and Management* (2012), 277-295. https://doi.org/10.5822/978-1-61091-229-7_17

designed to minimise stress to aquatic fauna by maintaining ambient flow velocities through the gate aperture. Unlike traditional buoyancy controlled tidal floodgates, the SwingGates operate in either a fully open or fully closed condition, thereby reducing drag on the gate, as well as maximising the opening area during operation. Stages 2 and 3 are separated by natural topographic features and internal floodgated culverts. Stage 3 was commissioned by the modification of standard floodgates to incorporate a manually operated orifice sluice gate. This structure is located immediately upstream of the Stage 2 buoyancy controlled SwingGates and regulates water levels within the Stage 3 restoration area.

1.5 Methods used to measure and value the restoration project

The approach used in this study to report on the value of Blue Carbon ecosystems is based on the System of Environmental Economic Accounting Ecosystem Accounting (SEEA–EA) method developed by the United Nations Statistical Commission[10]. While there are other approaches that can be used for ecosystem accounting, the SEEA–EA approach has been adopted to inform policy in more than 92 nations, and therefore has global recognition. It employs a rigorous approach to building accounts that can be used to inform decision-making by allowing cost-benefit analyses or increasing broader awareness of the value of ecosystems. This approach was also specifically used for Blue Carbon ecosystem restoration in the Guide.

Various methods are used to measure and estimate the changes to ecosystem extent and condition as well as changes to the ecosystem services produced on the site following restoration. These are described in detail in subsequent sections.

Figure 1.3: SwingGates at Tomago Wetlands.

[10] United Nations. "*System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA). White cover publication, pre-edited text subject to official editing*" (2021). https://seea.un.org/ecosystem-accounting

1.6 Aims of case study

The aims of this case study are:

- To test the process and methods recommended in the Guide to a completed restoration project. The Guide was in draft form when this case study was implemented. The experience of applying the Guide to a site allowed the authors to better refine its detail and guidance for application to future restoration projects.
- To facilitate the development of a set of output SEEA tables from a restoration site, which are included in this document.

One important contextual difference between this application of the Guide and future uses of the Guide is that we expect future users to apply the Guide to projects that are being planned or are newly commenced. These projects would apply the relevant monitoring approaches from the Guide to collect baseline data prior to restoration and capture the changes produced from restoration over time (planned).

However, to demonstrate the before and after effects of restoration when the Guide is applied, this case study relied on historical data from commencement of the restoration project until today (unplanned). As a result, monitoring requirements at the case study site were not set with the goals of the Guide in mind. Thus, some of the challenges experienced in this case study will differ from those using the Guide in future.

2. Analysis and design

The initial steps of the Draft Guide provide the framework for implementing an assessment of a restoration project; elements that define the scale and scope of the project, which are then used in subsequent measurement of project impacts. The steps of this process are presented in **Figure 2.1**.

In this section, we discuss the project team's experience in defining these aspects and define the outputs themselves for the Tomago wetland assessment.

2.1 Step 1: Project scoping & framing

As per the Guide, the first step in implementing an assessment of a blue carbon restoration project is to define the project scope and frame, including the following components:

Spatial coverage

A spatial coverage must be defined that captures the extent of impact of the restoration project.

As the objective of the restoration project was to increase the saltmarsh extent within the restoration site, the spatial coverage of this case study was limited to the areal extent of the restoration site boundaries (**Figure 2.1**). It was expected that all the significant impacts measured in the subsequent analyses occur within this area, with the exception of the increase in fish stocks that the project produces. While the project provides fish nursery benefits, juvenile fish leave the site and add to commercial and recreational fish harvests as an 'export' from the site (in SEEA terms), and the fishery productivity benefit would also come from primary production that flows into the main estuary system.

Other site exports will occur, for example improvements in water quality, however their effects were not a major objective of the restoration project, and so the principal drivers of change in value were believed to be constrained to the restoration site boundaries.

Temporal coverage

The prescribed temporal coverage of these case studies defined in the project Terms of Reference was to have two snapshots; one representing the site before intervention, and one after. Projects using the Guide may wish to have additional timepoints where accounts are assessed so that trajectory of change may be measured, especially for systems that are subject to inter-annual variation. In this case study, however, only the 'sum' effects of the rehabilitation were measured, therefore only two timepoints were assessed.

Restoration commenced on the project site in 2007, and data are in many cases available up to 2022, and so these two years were selected as the start and end points of the case study. For data points that are not available for 2022, team members have projected data forward to 2022. As stated previously, this is due to the retrospective nature of this case study. As outlined in the Guide, we recommend collecting data from the project site within the same accounting period where possible.

1. Project scoping and framing

2. Account design

3. Identify and collect data

4. Account compilation

5. Repeat data collection and account compilation

6. Report results

Define:

1. Spatial coverage
2. Temporal coverage
3. Ecosystem assets
4. Metrics to be used for measuring condition
5. Ecosystem services of interest
6. Benefits and beneficiaries

Data collection methods for each component:

5. Ecosystem extent
Using pre-existing products or one of many Earth observation data options available, map the extent change of ecosystems in the project area using the Global Ecosystem Typology.

6. Ecosystem condition
Using a conceptual understanding of the ecosystems in question, develop a list of variables that can be measured against a baseline to inform ecosystem condition.

Ecosystem services - physical ( ) & monetary ( )

7. Global climate regulation - Carbon stocks, sequestration and emissions
Carbon sequestration and stocks can be estimated using BlueCAM, but some situations may require on-ground measures. They are typically reported as tonnes Carbon per ha, and can then be upscaled across the site using ecosystem extent. CO_2e (physical) converted to $ (monetary) using ACCU carbon price.

8. Water purification services
Using equations provided and information on inflow nutrient concentrations, inundation frequency, and extent, soil carbon and vegetation cover, the total N and P removed can be estimated and valued using an appropriate price on N and P.

9. Coastal protection: erosion, storm mitigation, and flood control services
Decide which of the three potential components of coastal protection (if any) is applicable to your site, then use a mixture of measurement and modelling to estimate. Value using Annual Average Damages or Replacement Cost.

10. Nursery population and habitat maintenance service
This represents the contribution to populations of fish and invertebrates, prior to them contributing to other services (e.g. commercial fisheries or tourism). Measured using field surveys or monitoring.

11. Fisheries biomass provisioning service
Measured using fisheries catch data, data on diet compostion (from stable isotopes), and extent of ecosystems. Valued using Gross Value of Product and total economic output.

12. Cultural services: recreation and non-use values
Measured using site-specific data collection or benefit transfer based on the most important values of the site. Currently, the SEEA framework only includes exchange values in te monetary account, such as values from direct visitation.

13: Cultural services: First Nations values
Indigenous worldviews are holistic, with individual services difficult to quantify on their own. However, Indigenous values are many and varied, and thus values to be measured need to be developed and co-designed with the relevant Indigenous groups/representatives and a 7-step process of data collection.

Environmental protection accounts

14 Restoration activities
Measured based on the physical actions at the site, but also project management and engagement as necessary for the specific project.

15 Restoration activities
The exchange values of the physical activities in 14.

Figure 2.1: Steps in compiling site-level environmental economic accounts of blue carbon ecosystems, integrating the steps from the SEEA-EA framework with the detailed methods considered here. Accounts where physical services are quantified is denoted by the tree icon and accounts where monetary services are quantified denoted by the money icon.

Ecological extent and condition

While we expect future users of the Guide to be planning or commencing new restoration projects, this case study was confined to using existing data from a project which commenced many years ago, and as such identifying how the project has led to changes in ecological extent and condition was facilitated by historical data available from the inception of the restoration project. Ecological extent of habitats was in this case measured exclusively from satellite imagery, with some ground validation undertaken of the current extents.

Ecological condition is a complex component of EEA that needs to be defined at the commencement of a restoration project to provide a baseline measure and to identify success targets (see **Section 3.1** for more discussion). In some instances, e.g. in this case study where assessments are being made post-hoc, condition will be assessed in the context of anticipated outcomes of restoration. We suggest users undertake scoping prior to selecting condition metrics and commencing condition assessments. For example, the purpose of restoration should be characterised, and the selection of indicators undertaken only after the anticipated outcome of restoration is defined. Specific indicators of condition can then be selected that align with the purpose and proposed outcome. As per best practice, selection of condition metrics should follow the SMART principles of monitoring and evaluation, which specifies that indicators should be specific, measurable, achievable, relevant and time-bound (SMART). Following these principles when selecting condition metrics will ensure that indicators are well-defined, relate to the purpose and proposition, and can be effectively applied to measure progress towards the proposed outcome of restoration.

Ecosystem service scoping

While users of the Guide will scope out the intended impacts of the restoration activities and the ecosystem services that they expect to enhance through restoration, for this case study the restoration activities have taken place for 15 years and the ecosystem services to be considered were defined in the project Terms of Reference, including:

- Fish nursery
- Fish biomass provisioning
- Recreational activities
- Carbon sequestration and emissions
- Coastal protection

Effects of intervention

Knowing the method of restoration intervention can help to identify the likely effects of restoration on extent and condition of ecosystem stocks, and ecosystem services. The effects that drive the changes in ecosystem function should be identified as the most important to measure. This is particularly relevant for defining indicators of 'ecosystem condition' to measure, as positive and negative indicators of condition are likely to be defined relative to the intention of intervention. Since this project was reliant on using existing data, it was simple to identify the effects of intervention. However, for those using the Guide, should follow the method there, to develop a conceptual model based on expert advice to identify the likely effects of intervention.

In this system, installation of floodgates led to changes in tidal height and exposure. This had the effect of increasing salinity at higher tide levels, which was the driver for most of the change observed within Tomago wetland. Changes included losses of pasture ecosystem, significant increases in saltmarsh extent within the restoration site, and more inundated habitats. These effects led to flow-on changes to condition, habitat extent, and ecosystem services within the rehabilitation site.

Stakeholder mapping

Identifying stakeholders to consult is critical to best understand the effects of the project, collect relevant data, and provide a social license for restoration approaches (Table 2.1).

Table 2.1: Key stakeholders engaged

Stakeholder	Role
NSW Department of Primary Industries – Fisheries	Restoration activities and costs
NSW Department of Primary Industries	Provision of recreational fishing survey data Consultation on measures of the contribution of restoration site for fish biomass productivity
NSW National Parks and Wildlife Services	Restoration activities and costs
James Cook University – Global Ecology Lab	Extent and Condition - saltmarsh mapping
Hunter Wetlands Centre Australia	Consultation on birdwatching activities in the Tomago wetland
Water research Laboratory, University of New South Wales	Provision of anecdotal evidence on birdwatching activities in the Tomago wetland Provision of data on restoration costs Provision of data on tidal range
Hunter Bird Observers Club	Consultation on birdwatching activities in the Tomago wetland
OceanWatch	End-user consultation
University of Adelaide	Consultation with coastal wetland experts
Queensland Department of Environment and Science	Government agency
CSIRO	Developers of tools to predict benefits

2.2 Step 2: Account design

Outputs from project scoping were used to inform the account design, particularly the temporal and spatial coverage. As noted, the scope of ecosystem assets and services to include were defined in the project Terms of Reference (see **Glossary**).

Final temporal and spatial scope were as defined in the scoping stage (2007/2022; project boundaries).

Account structures: the project team drew upon three main types of physical ecosystem accounts - ecosystem extent and ecosystem condition, and ecosystem supply and use tables. Draft tables were drawn from the first Draft of the Guide, to be tested in this analysis. Final tables can be found in **Sections 3** and **4**.

Each project sub-team used this information and table structures as a starting point for their analysis, producing the analysis and results found in subsequent report sections.

2.3 Step 3: Identify and collect data

Evaluation of the restoration project impacts requires a broad range of datasets across the ecosystem service areas mentioned in **Section 2.1** above, underpinned by relevant indicators of ecosystem extent and condition.

Lead authors from the University of NSW have been directly involved in the restoration of the Hunter River Estuary since the commencement of the restoration project and have worked in the region for several decades. In addition, many of the authors have worked on their subject matter area in the site area and surrounding region over a similar period.

Therefore, the majority of existing relevant datasets were already in the possession of the authors, others were sought under the direction of the lead authors.

Given the short time period available for this case study, primary data collection was not possible. Some stakeholder engagement was undertaken by the recreational services team to provide bird watching and recreational fishing incidence estimates. Benefit transfer data from published literature was also used.

3. Ecosystem extent and condition

This section provides detailed information on the methodologies used to assess the biophysical and economic impacts of the restoration project, as well as detailed results and discussion related to each major section of analysis. This corresponds to Steps 4 and 5 of the Guide: account compilation, and repeat data collection and account compilation (noting again that this case study was restricted to existing data, so the authors assembled 'before' and 'after' restoration accounts).

The section starts with extent and condition accounts, which are then used to produce ecosystem services accounts.

3.1 Extent account

Intent of work

A key measure of the success of restoration activities in blue carbon ecosystems is the change in areal extent. *Ecosystem extent* is defined as the size of an ecosystem asset, with the assets in this case being ecosystems within the project area. *Ecosystem conversion* is defined as the conversion of 'other' ecosystems to coastal ecosystems (or vice-versa), and this is determined by quantifying coastal ecosystem extent before and after a restoration activity[11].

Quantifying coastal ecosystem extent change for environmental economic accounts can be undertaken using remote sensing to define vegetation community boundaries, produce maps of vegetation community distributions and measure extents. Remote sensing approaches can be cost effective, reproducible and standardised, and are effective for measuring coastal ecosystem extent and changes in extent over time. For project level environmental economic accounts, extent calculations are influenced by the resolution of Earth observation data, mapping approaches and overall accuracy of vegetation community boundaries. However, production of highly accurate maps should be balanced against the costs and expertise of production, and to ensure sufficient rigour is maintained. In addition to potential data limitations, site reconnaissance prior to data collation and analysis is recommended to assess the suitability of the proposed method and the feasibility of success.

For the Tomago restoration activities at Hunter River, change in ecosystem extents of mangrove, saltmarsh, supratidal forests, intertidal seagrass, intertidal mudflats, and conversion of 'other' ecosystems', primarily pasture, was the focus.

Approach taken

The Hunter River provides an excellent example of project-level environmental economic accounting with substantial existing datasets to calculate extent. For this assessment, both a nationally consistent approach that relies upon available national products and a detailed approach that uses higher resolution site-specific products are provided. Two approaches were applied to assess the different outcomes from undertaking a detailed site-specific assessment versus a site-specific assessment derived from national products. The nationally consistent approach

[11] Keith, H., et al. "A conceptual framework and practical structure for implementing ecosystem condition accounts." *One Ecosystem* (2020), e58216. https://doi.org/10.3897/oneeco.5.e58216

made use of several publicly available datasets supplemented with datasets currently in development that will become publicly available. These are produced using Landsat with a cell size of 30 m. All analysis was undertaken in Geosciences Australia Digital Earth Australia Sandbox (hereafter DEA sandbox), where necessary data is freely available. However, these analyses could also be undertaken in a desktop GIS platform with data downloaded. When all pre- and post-restoration datasets for coastal and 'other' ecosystem types were generated as raster layers, pixel counts for each ecosystem type were summed to provide areal extent (ha). This was input into the SEEA-EA tables where post-restoration extent was subtracted from pre-restoration extent to indicate net change in ecosystem extent.

The detailed approach focused on incorporating small-scale changes in extent that influence the overall extent of each land cover class. These changes may not be obvious using the national approach, which has a larger 30 m resolution. There were several existing datasets that were considered, each with varying levels of suitability and accuracy. For the detailed approach pre- and post-restoration vegetation extent maps were created using publicly available historical aerial imagery, a digital elevation model (DEM) derived from light detection and ranging data, and Nearmap aerial imagery. Analysis was undertaken using ArcMap and eCognition software; however, this approach could be reproduced using open-source software such as QGIS and DEA sandbox. Vegetation extent maps were produced using a multiresolution segmentation approach and a supervised classification for both pre- and post-restoration time periods. The area (ha) of each land cover was calculated in ArcMap using the calculate geometry tool. This was input into the SEEA-EA tables where post-restoration extent was subtracted from pre-restoration extent to provide net change in ecosystem extent.

Results

The restoration activities led to an increase in areal extent of saltmarsh, supratidal forests and waterbodies/mudflats, with a concomitant decrease in 'other ecosystems'. For the nationally consistent approach, restoration activities resulted in ecosystem conversion with an increase in blue carbon ecosystem extent of 45.9 ha. This was due to an increase in saltmarsh ecosystem extent (35.5 ha) and an increase in supratidal forest extent (10.4 ha). A large decrease in other land covers was detected (91 ha) as well as an increase in the areal extent of waterbodies/mudflats present (45.1 ha). Intertidal seagrass and intertidal mudflats were not detected within the restoration site boundary.

For the detailed approach, restoration resulted in an increase in blue carbon ecosystem extent by 198.14 ha. This was due to an increase in saltmarsh extent (140 ha) and supratidal forests (58.3 ha). The increase in these land covers was due to replacement of grass (108 ha) and dry scrub and cleared land (153 ha). Mangrove and intertidal seagrass extent was not included as they did not occur within the restoration area. Different classes were detected pre- and post-restoration due to the resolution and suitability of the data layers and the availability of existing detailed vegetation maps to help guide the classification process.

Reflection relative to the Guide

Here, two approaches to quantifying extent, the national and detailed approaches, were undertaken. There were differences in extent between these approaches, which was anticipated given the differences in spatial resolution between the national and the detailed assessments. While the detailed approach that uses higher resolution site-specific information may provide more accurate quantification of ecosystem extent compared to the national approach, this was not possible within the scope of this case study that was reliant on using existing data, and detailed ground validation of extent pre-restoration was not possible. Moreover, the capacity to detect ecosystems, and the precision in doing so was anticipated to be greater in the detailed approach, and we would expect higher confidence in this approach. However, in many locations, the detailed approach may not be a viable for new projects where issues with data availability or cost limitations occur. It is in these situations that the national approach should be undertaken.

We would recommend using the detailed approach wherever possible, however, if high resolution data or expertise are not available the national approach demonstrated here and outlined in the Guide can be used. If data collection occurs prior to restoration, we advocate using aerial photography from Nearmap, or collecting imagery using a remotely piloted aircraft.

3.1.1 Extent account supplementary material

National approach to extent mapping

Data availabilty

For the nationally consistent approach, several publicly available datasets were used as well as some currently in development that are due to be publicly released in 2023. These were produced using Landsat with a cell size of 30 m. Pre- and post-restoration years were identified to calculate extent of ecosystems in 2005 and 2021, respectively. All analyses were undertaken in the DEA sandbox (https://docs.dea.ga.gov.au/setup/Sandbox/sandbox.html), where all necessary data is freely available; however, analyses could also be undertaken in a desktop GIS platform with data downloaded from a relevant archive.

- Mangroves: DEA Mangroves (https://cmi.ga.gov.au/data-products/dea/634/dea-mangrove-canopy-cover-landsat).
- Saltmarsh: Australian Saltmarsh Map (https://www.saltmarshes.org/home). This product will be publicly available in 2023.
- Supratidal forests: An Australia-wide product is currently in development by the authors. Test outputs have been generated for the Tomago restoration boundary. This product will be publicly available in 2024.
- Intertidal seagrass: IMAS Seamap (https://seamapaustralia.org/map/)
- Waterbodies/Mudflats: DEA Land Cover (https://www.dea.ga.gov.au/products/dea-land-cover).
- Mudflats: Global Intertidal change (https://www.intertidal.app/).
- 'Other' ecosystems: DEA Land Cover (https://www.dea.ga.gov.au/products/dea-land-cover).

Methods

Many of the nationally consistent datasets are available at annual time-steps, or with the prospect of potentially becoming available annually. The before and after restoration years were initially identified; 2005 and 2021, respectively. Where annual data was not available for these years, datasets temporally near these years was considered fit for purpose (i.e. 2022 dataset). The project site boundary was then defined based on where restoration activities were undertaken. All analyses were undertaken in the DEA sandbox (https://docs.dea.ga.gov.au/setup/Sandbox/sandbox.html), where necessary data is freely available; however, could also be undertaken in a desktop GIS platform with data downloaded (see links above). Details of analysis steps for each layer are described below:

Mangroves:

- Site boundary used to extract area of interest from DEA Mangrove Canopy Cover datasets for 2005 and 2021.

Saltmarsh:

- Site boundary used to extract area of interest from the Australian saltmarsh map (2022 snapshot, used as post-restoration dataset).
- Pre-restoration dataset generated by hindcasting the Australian saltmarsh map modulated with the annual Woody Vegetation Cover Fraction (WCF - http://wenfo.org/tree/)for 2005. To obtain likely non-woody vegetation within the Australian saltmarsh map, thresholds were set on the WCF layer, whereby saltmarsh was considered present if WCF > 0.05 and WCF < 0.4.

Supratidal forests

- Calculated by combining DEA Mangroves, Woody Vegetation Cover Fraction (WCF), Shuttle Radar Topography Mission (SRTM), and Intertidal Extent Model (ITEM) using a rule-based approach. WCF threshold was set to > 0.5 based capturing vegetation that were likely to be woody (i.e. shrubs/trees). SRTM elevation data was used to limit extent of supratidal forests to an expected common range based on existing literature and field surveys (1 m – 10 m AHD). DEA Mangroves and ITEM were used to mask areas considered mangrove ecosystems or intertidal areas.
- Pre- and post-restoration datasets were generated using annual available datasets (e.g. DEA Mangroves, WCF) for 2005 and 2021.

Intertidal seagrass

- Site boundary used to extract area of interest from the Australian intertidal seagrass dataset (2019-2020 snapshot, used as post restoration dataset).
- No pre-restoration nationally consistent dataset was available.

Waterbodies/Mudflats

- Site boundary used to extract area of interest of DEA Land Cover annual dataset for 2005 and 2020.
- Waterbodies land cover class extracted out for both datasets.

Intertidal mudflats

- Site boundary used to extract area of interest from the Global intertidal change dataset for pre- and post-restoration (2005 and 2014, 2021 not available and 2014 substituted).

Other land covers

- Site boundary used to extract are of interest of DEA Land Cover annual dataset for 2005 and 2020.
- Cultivated areas, bare areas and artificial surface land cover classes extracted for both datasets.

When all pre- and post-restoration datasets for coastal and 'other' ecosystem types were generated and compiled as raster layers, these were combined to produce pre- and post-restoration maps (**Figures 3.1** and **3.2**). As several datasets were used to generate extents for each ecosystem type, conflicting attributions were identified (e.g. where a cell was classified as both mangrove and saltmarsh). To ensure each cell within the study boundary was only attributed to one ecosystem type, as required for SEEA-EA, a layer priority was formulated whereby if a cell was identified as more than one ecosystem type, the highest priority layer was given preference and the pixel labelled accordingly. This order of layer priority was based on confidence in accuracy of a dataset according to whether the dataset was well-established, publicly available, peer-reviewed, and operationalised at national scale. For the Tomago restoration site, order of layer priority was mangrove, followed by waterbodies/mudflats, other land covers, mudflats, intertidal seagrass, saltmarsh, and supratidal forests. In addition, where cells within the Tomago restoration boundary were not identified as an ecosystem type (i.e. unclassified), these were considered as 'other' land covers.

Pixel counts for each ecosystem type were summed to provide areal extent (ha) for input into the SEEA-EA table (**Table 3.1**) where post-restoration was subtracted from pre-restoration to provide net change in ecosystem extent.

Results

Restoration activities demonstrated an increase in blue carbon ecosystem extent of 45.9 ha (**Table 3.1**). This was primarily due to an increase in saltmarsh ecosystem extent (35.5 ha) with an increase in supratidal forest extent also being a contributing factor (10.4 ha). A substantial decrease in other land covers was detected (91.0 ha), as well as an increase in the areal extent of waterbodies/mudflats (45.1 ha), and mangrove ecosystem extent did not change. Intertidal seagrass and intertidal mudflats were not detected within the restoration site boundary.

Interpretation and discussion

**The text in this sub-section represents the professional opinions of the authors of this section of the case study and does not represent the views of DCCEEW.*

While the standard SEEA-EA table format provides a gross indication of the change in extent, it does not provide sufficient spatial information to ascertain whether the changes in extent occurred in anticipated locations, or were contrary to the restoration target. Therefore, in addition to the standard SEEA-EA extent table, we recommend projects complete an ecosystem type change matrix (Table 4.2 in the SEEA-EA guidelines), which can also be displayed via maps.

There were also issues with accounting for the influence of climatic variability on some land cover classes. In particular, the extent of standing water changed remarkably over the study period, with high standing water during La Niña periods, and low standing water during El Niño periods. The outcome of this variation is that the opening or closing dates may align with one of these extremes, and the reported extent may not sufficiently represent the trajectory of change over the study period. This variation should be quantified in some manner, or at least acknowledged as a footnote in the tables.

When using multiple datasets to quantify extent, as was undertaken at the national scale, it is important to be aware of the accuracy and precision in the datasets. In some cases, the accuracy may be low, and when there are multiple datasets with moderate to low accuracy being used, the errors may be substantial. This is difficult to overcome at this national scale, but should be sufficiently acknowledged. To assess the overall influence of accuracy and precision errors, the extents could be compared against the global wetland change product to provide a first order validation.

Several assumptions were necessary, such as the layer prioritisation that was undertaken. This was an essential step that was undertaken at our discretion, but informed by knowledge of the changes that were expected to occur during the restoration activity. Consideration should be given to layer prioritisation.

Table 3.1: Change in extent (ha) of different ecosystem types pre- (2005) and post- (2021) restoration actions being undertaken at Tomago using the National approach (30 m resolution)[12].

	Selected ecosystem types (based on Level 3 -EFG of the IUCN Global Ecosystem Typology)						Total blue carbon ecosystems	Total ecosystem extent
Realm	Marine-Freshwater-Terrestrial			Marine	Marine-Terrestrial	Terrestrial		
Biome	MFT1 Brackish tidal			M1 Marine shelf	MT1 Shorelines biome	T7 Intensive land use		
Selected Ecosystem Functional Group (EFG)	Mangroves MFT1.2*	Saltmarsh MFT1.3	Supratidal forests MFT1.2*	Intertidal seagrass M1.1	Muddy shorelines** MT1.2	Other land covers T7.1		
Opening extent (pre-restoration)	3.96	102.51	33.12	-	0.00	159.21	139.59	298.80
Additions to extent	0.00	35.46	10.44	-	45.09	0.00	45.90	90.99
Reduction to extent	0.00	0.00	0.00	-	0.00	90.99	0.00	90.99
Net change in extent	0.00	35.46	10.44	-	45.09	-90.99	45.90	0.00
Closing extent	3.96	137.97	43.56	-	45.09	68.22	185.49	298.80

[12] *Supratidal forests technically are classified within the same category as mangroves (Intertidal forests and shrublands MFT1.2), but have been split here.

Intertidal seagrass and mudflats were not detected within restoration activity boundary.

**Muddy shorelines=waterbodies.

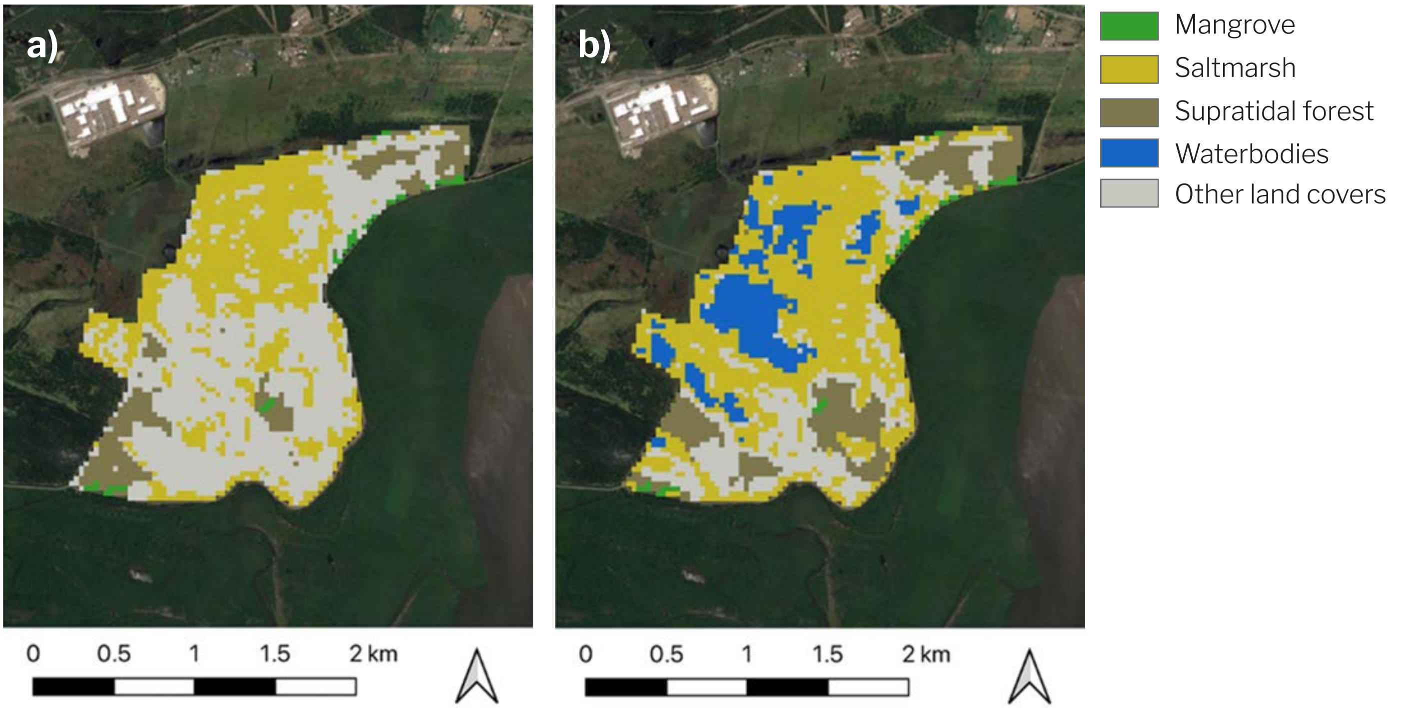

Figure 3.1: **Tomago ecosystem extent a) before (~2005) and b) after (~2021) restoration activities using the National approach (30 m resolution).** Waterbodies=mudflats.

Detailed approach

Data availabilty

Datasets for Tomago pre-restoration (i.e. pre-2007) were limited in terms of their accuracy and suitability. For example, many of the Hunter region vegetation maps prior to 2007 did not include Tomago, instead focusing on Hexham Swamp and Kooragang Island. The site boundary for the national and high accuracy approach was the same to ensure consistency between methods and results.

The pre-restoration vegetation mapping available for Tomago, prepared by Geoffrey Winning in 1993 for NSW National Parks and Wildlife Service, was not suitable as vegetation categories were not distinct enough for the EEA reporting, combining ecosystems such as mangrove/scrub. In addition, there were overlapping classes, with some areas identified as 'mangrove/scrub' and '*Agrostis avenacea*, *Sporobolus virginicus*, *Juncus spp.*, *Cynodon dactylon*, *Paspalum spp.*, *Senecio madagascariensis / Bolboschoenus caldwellii - Sporobolous virginicus*, *Phragmites australis*, *Juncus spp*'. Other vegetation maps such as NSW Estuarine Macrophyte mapping available via DPI Fisheries (https://datasets.seed.nsw.gov.au/dataset/estuaries-including-macrophyte-detail5ebff) was also not ideal as the data layers significantly underestimated the area of saltmarsh. The most suitable existing vegetation mapping was conducted in 2016 (within 6 months of completion of the restoration project) prepared by Kleinfelder Consulting for NSW National Parks and Wildlife Service. This data was used to guide the supervised classification and manual consolidation process.

Methods

Object based image assessment (OBIA)

To produce improved pre-restoration vegetation maps (**Figure 3.2**), 2001 historical aerial imagery obtained via the NSW Government spatial data portal (https://portal.spatial.nsw.gov.au/portal/), was used with a 2007 digital elevation model (DEM) to perform an object-based image analysis (OBIA) in eCognition software. The same approach was used to map post-restoration vegetation extent using 2021 Nearmap aerial imagery and 2014 DEM data.

OBIA is a type of image analysis that groups cells into objects (i.e. vectors) based on their spectral, geometrical and spatial properties to partition and classify Earth observation data. This method is often used as an alternative to traditional image classification approaches that assign a land cover class per cell (same size and shape), without considering neighbouring cells.

Firstly, the aerial image and DEM were projected to WGS 1984 UTM Zone 56S in ArcMap before being imported to eCognition. A multiresolution segmentation was applied to split the area of interest into objects (based on spatial and spectral properties) representing land covers. To achieve the most accurate segmentation the following parameters were adjusted: 'scale' which controls the spatial and spectral homogeneity of objects; 'shape' which defines the influence of spatial and spectral homogeneity of objects; and 'compactness' which indicates the influence of smoothness and compactness of objects. In this study the following parameters were chosen: scale parameter: 100; shape: 0.3; and compactness 0.8. The objects were then classified using their shape, size, spatial and spectral properties. A supervised classification was conducted, with representative samples chosen for each class to direct the processing software to use these training sites as references for all the other cells across the image. Samples were selected based on expert opinion from scientists who regularly visit the area and the post-restoration imagery was informed by vegetation mapping from Kleinfelder (contractors), 2016.

The delineated objects (i.e. vectors) were used to calculate extent for each habitat type pre- and post-restoration using the 'Calculate Geometry' tool in ArcMap. This provides the areal extent in hectares. The post-restoration area can be subtracted from the pre-restoration area to calculate net change in extent. The classes for pre- and post-restoration can be seen in **Table 3.2**, along with the associated extent (area ha). There are different classes pre- and post-restoration due to the different resolution of the input data layers and the fact that the landscape has changed over time, primarily with the replacement of grass and scrub with saltmarsh.

To ascertain the accuracy of the post-restoration vegetation map, a Remotely Piloted Aircraft (RPA) survey was conducted on 2nd February 2023 to obtain aerial images. Images were collected using a DJI real time kinematic global positioning system (RTK-GPS) Phantom 4 RPA. Images consisting of red, green and blue (RGB) spectral bands were taken at a height of 60 m with a 24 mm wide angle camera with a one-inch complementary metal oxide semiconductor (CMOS) sensor. The images were used in Agisoft Metashape Professional to create an orthomosaic. The accuracy of the post-restoration vegetation mapping, based on the RPA orthomosaic was 81 %, with Users' and Producers' accuracies ranging from 74.5 to 86.3 % and 61.4 to 79.2 %.

Results

For the detailed approach restoration resulted in an increase in blue carbon ecosystem extent by 198 ha. This was primarily due to an increase in saltmarsh extent (140 ha) and to a lesser extent supratidal forests (58.3 ha). The increase in these land covers was primarily due to replacement of grass (108 ha) and other land covers (153 ha), which included dry scrub. Mangrove and intertidal seagrass extent was not included as this is outside the boundary of the restoration area. Different classes were detected pre- and post-restoration due to the resolution and suitability of data layers and the availability of existing detailed vegetation maps to help guide the classification process.

Interpretation and discussion

The detailed approach allows for small changes in the landscape to be identified, this is useful for natural resource managers tasked with understanding the location and types of on ground management works to prioritise in the future. The detailed maps of extent also allow for saltmarsh, mudflats, and ponds to be identified in the post-restoration phase. However, the primary limitation for the detailed approach was data availability, particularly pre-restoration. Without detailed existing maps of vegetation or high-resolution imagery it was too difficult to discriminate small areas of saltmarsh that may have been present. In addition, without high resolution spatial or field data, confidence in mapped extents derived from image classification is low. Future restoration projects should ensure comprehensive data collection is conducted prior to the onset of restoration activities. Useful data collection may include remotely piloted aircraft (i.e. drone) aerial flights and georeferenced quadrat/transect field measures of species and biomass.

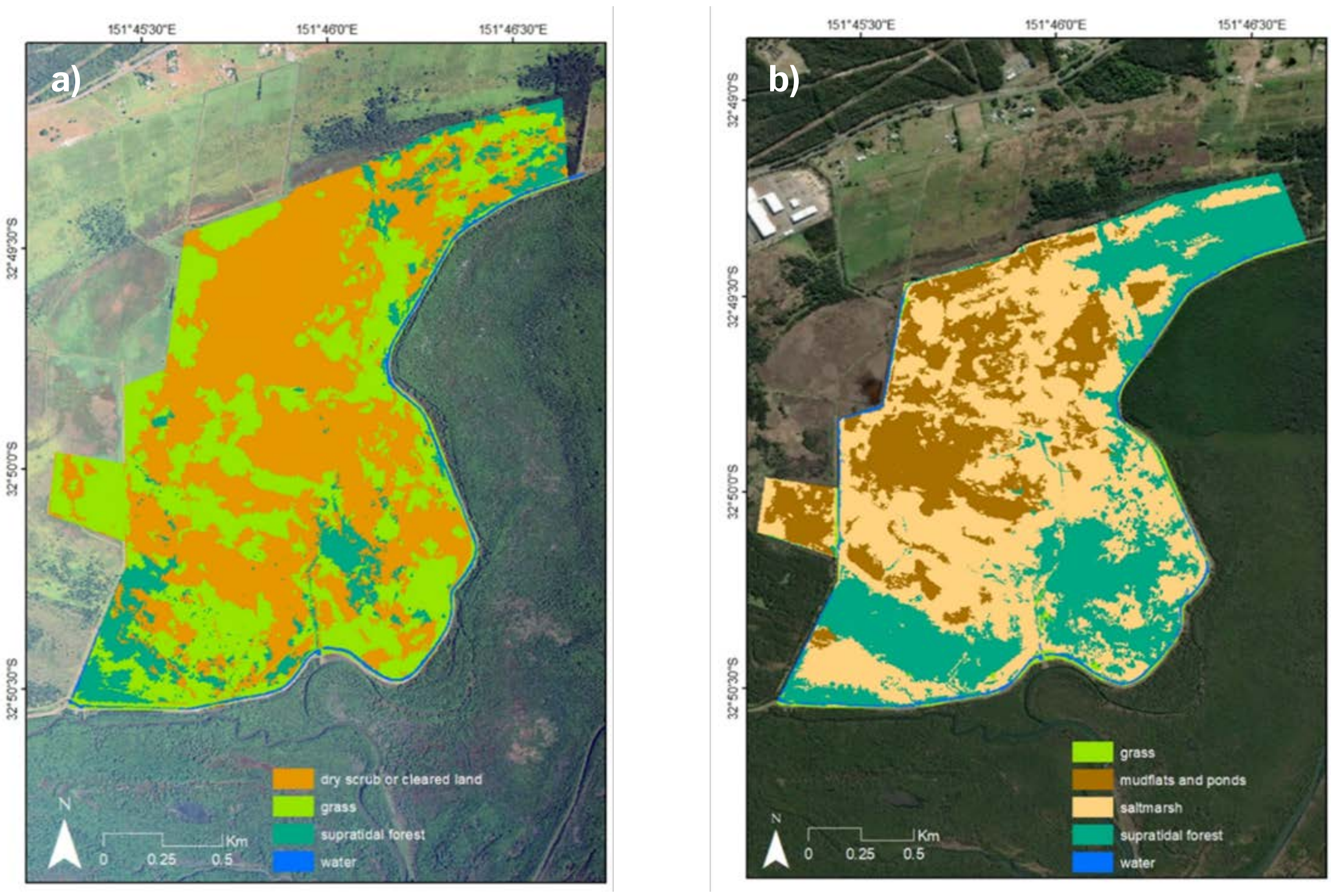

Figure 3.2: Tomago vegetation extent a) pre- (~2007) and b) post-restoration (~2021) activities using the detailed approach.

Table 3.2: **Table showing change in extent (ha-1) different ecosystem types before (~2007) and after (~2021) restoration actions have taken place using the detailed approach.** Intertidal seagrass and mangroves were not detected within restoration activity boundary (Environmental Accounting Area).

	Selected ecosystem types (based on Level 3 -EFG of the IUCN Global Ecosystem Typology)							Total blue carbon ecosystems	Total ecosystem extent
Realm	Marine-Freshwater-Terrestrial			Marine	Marine-Terrestrial	Terrestrial			
Biome	MFT1 Brackish tidal			M1 Marine shelf	MT1 Shorelines biome	T7 Intensive land use			
Selected Ecosystem Functional Group (EFG)	Mangroves MF1.2	Saltmarsh MFT1.3	Supratidal forests MFT1.2	Intertidal seagrass M1.1	Mudflats MT1.2	Grass T7.2	Dry scrub and cleared land T7.5		
Opening extent (pre-restoration)	-	0.00	29.89	-	4.51	111.98	153.44	29.89	299.80
Additions to extent	-	139.87	58.27	-	63.5	0.00	0.00	198.14	261.64
Reduction to extent	-	0.00	0.00	-	0.00	108.19	153.44	0.00	261.63
Net change in extent	-	139.87	58.27	-	63.5	-108.19	-153.44	198.14	0
Closing extent	-	139.87	88.16	-	68.01	3.79	0.00	228.03	299.80

3.2 Condition account

Intent of work

Ecosystem condition is key to restoration planning, implementation, and monitoring and evaluation of restoration success. Ecosystem condition is defined as 'the quality of the ecosystem measured in terms of its abiotic, biotic and landscape/seascape characteristics'[13]. Measures of condition are ecosystem-specific and should have a conceptually similar reference baseline as the basis for developing indicators of condition. This reference state is often 'natural'; in an Australian context, this is typically an estimate of pre-European colonisation state, based on sites representing 'best of what's left'. Identifying the change in condition of vegetation-based communities requires more information about the ecosystem that is not described by measurements of ecosystem extent.

[13] United Nations. "System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA). White cover publication, pre-edited text subject to official editing" (2021). https://seea.un.org/ecosystem-accounting

Condition accounts are made up of ecosystem-specific variables that cover many ecosystem attributes (composition, structure and function, as well as landscape context and connectivity, across biotic and abiotic components of the ecosystem). Measurements of variables are often converted into indicators, by normalising variables to values scaled between 0 and 1. The reference state is an exemplar of high condition (e.g. a value of 1) and a transformed or extremely degraded state is low condition (e.g. a value of 0). Collating ecosystem condition variables can be from many data sources, including field-based data, remotely-sensed data, expert judgement and modelling. For this case study, remote sensing was used to inform pre- and post-restoration condition due to limited pre-restoration field-based data collection on ecosystem condition. For project level environmental economic accounts, ecosystem condition variables calculated from remote sensing data are influenced by the resolution of Earth observation data, mapping approaches and overall accuracy of vegetation community boundaries. However, production of highly accurate maps should be balanced against the costs and expertise of production that would be needed to provide sufficient rigour. In addition to potential data limitations, assessment of the capacity of condition variables to provide meaningful and useful information about condition for a restoration site should be assessed in advance of data collation and analysis.

For the Tomago restoration activities, change in ecosystem condition of mangrove, saltmarsh, supratidal forests and conversion of 'other' ecosystems was the focus. Intertidal seagrass were not detected in the national approach extent calculations and therefore were not considered for national ecosystem condition calculations. Priority was given to the target ecosystems anticipated to be modified by the restoration activities, in this case, saltmarsh condition was prioritised, but the condition of other ecosystems was also considered.

Approach taken

Tomago provides an example of project-level EEA with existing datasets to calculate ecosystem condition. For this assessment, both a nationally consistent approach and a detailed approach were demonstrated.

For the nationally consistent approach, several publicly available datasets were used as well as some currently in development that will be publicly released soon. These were produced using Landsat images with a cell size of 30 m. Pre- and post-restoration extents for each ecosystem were combined to identify the mutually inclusive area (i.e. cells that were the same ecosystem type both before and after restoration activities). This was necessary for some condition indicators to ensure measurements of change in condition pre- and post-restoration were meaningful. Condition metrics were chosen based on their relevance to the restoration aims, technical accuracy and appropriateness for the data layers available. The metrics derived for each ecosystem type included age since restoration activities, vegetation cover, above-ground biomass (AGB), vegetation greenness, landscape wetness, and connectivity of ecosystem. All analyses were undertaken in the DEA sandbox (an open source learning and analysis environment provided by Geoscience Australia), where all necessary data is freely available. However, analyses could also be undertaken in a desktop GIS platform with data downloaded.

Condition variables were then transformed to scale between 0 and 1, where appropriate. The specific scaling was identified for each variable and each ecosystem type (process and rationale outlined in the Guide). All transformed pre- and post-restoration condition datasets for coastal and 'other' ecosystem types were generated as raster layers. Two approaches were then taken to report change in condition indicators. First, cell counts for each ecosystem type were totalled and averaged over the extent area. The mean value was input into the SEEA-EA tables where post-restoration was subtracted from pre-restoration condition variables to provide change in ecosystem condition for each indicator. Second, the direction of change in cell values (i.e. positive = increase in condition, negative = decrease in condition) was identified and summed up to provide a total change in area of the condition indicator. Negative change in condition indicator area was subtracted from positive change in condition indicator area to provide net change area of positive or negative condition change and reported in SEEA-EA tables.

For the detailed approach, assessments of condition relied upon using existing datasets to develop indicators of condition. However, high resolution datasets were limited, particularly datasets relevant to assessing pre-restoration condition. The approach used the detailed extent mapping in ArcMap to describe changes in land cover pre- and post-restoration and applied indicators to these extents, where suitable. The areas of land cover change were used to calculate vegetation biomass stocks (as Above Ground Biomass (AGB)). The difference in the AGB was calculated by subtracting post-restoration AGB values from pre-restoration AGB values. Other condition metrics were derived such as connectivity of the ecosystem using DEA sandbox and measures of productivity. Productivity measures used land cover age raster datasets, acquired from the national approach, a 2014 canopy height model (CHM) and publicly available 2018 AGB derived from the European Space Agency's (ESA's) Climate Change Initiative Biomass project (CCI Biomass). Increase in AGB was observed for supratidal forests, saltmarsh and other land cover datasets (using extents from the national approach). Condition variables were identified for each ecosystem, where possible, and mean values were added to Condition tables.

Results

For the nationally consistent approach, restoration activities demonstrated a marginal increase in connectivity of coastal ecosystems, and a decrease in connectivity of other land covers. An increase in saltmarsh AGB was detected, though other ecosystems remained constant. Supratidal forest cover and greenness increased post-restoration; however, decreases in vegetation cover and greenness for saltmarsh were detected. Many indicators demonstrated substantial spatial variability for coastal wetland ecosystems pre- and post-restoration activities, and generalised trends were difficult to establish.

For the detailed approach restoration activities resulted in a significant increase in the extent of saltmarsh and a reduction in area of dry scrub and grassland. Considering the aim of the restoration project was to convert drained grassland used for agriculture to saltmarsh for bird habitat, the change in land cover was colour coded according to a traffic light system (**Figure 3.15**). Similarly, a traffic light system was used to indicate areas of loss, gain and negligible change in above ground biomass stocks for each land cover change (**Figure 3.16**). There were significant gains in above ground biomass of supratidal forest caused by conversion from grassland and dry scrub. Large losses of above ground biomass were also caused by supratidal forest shifting to saltmarsh, grass and mudflats and ponds. Productivity measurements were only possible for some land cover classes due to the suitability of the data. For supratidal forests the canopy height model derived from 2014 LiDAR data was used with the age of the forest, to produce an average of 0.508 meters per year increase in height. The height per year value was derived per pixel for the post-restoration dataset (~2021 post restoration extent). Spatial variation in above ground biomass per year indicated the highest rates for saltmarsh. This value should be used with caution as it is likely an overestimation due to the relatively young age of this ecosystem.

Reflection relative to the Guide

Although an excellent option to apply a case study using existing data and the approach from the Guide, multiple issues emerged while compiling condition accounts. Initially we had ambitious goals, but there were considerable data availability and data quality limitations arising from relying on historical data that prevented this. There was limited access to LiDAR data, and the unavailability of LiDAR data that describes vegetation height changes over time. Ideally, we would recommend the collection of detailed datasets prior to undertaking restoration activities; these datasets would serve as a benchmark for monitoring changes through the reporting period.

It was also critical to ensure that condition indicators were meaningful for the restoration activities being undertaken (further described in the Guide). This required understanding of the restoration targets prior to selecting indicators.

There was some variability in condition indicators; however, it was difficult to assess whether this variability was because of errors in the dataset, the sensitivity of the indicator to detect changes, natural variability arising from climate change, or whether variation was in response to the restoration activity itself. Wherever possible, consideration should be given to all factors when reporting changes, and if the reported changes are arising from factors other than restoration success, these should be noted.

The reflection of the authors of this section is that on their own the standard SEEA-EA tables alone do not provide sufficient capacity to report on spatial changes in condition as part of this case study. In this case study we found the overall outcome of this is that the reporting can be too reductive, and minor successes at large scale can be masked by declines in condition occurring elsewhere in the project area. Thus, as outlined in the SEEA-EA guidelines and the Guide, the combination of using SEEA-EA tables and producing maps in parallel to highlight the more detailed condition changes is a complimentary approach to reporting condition accounts that is recommended for project-level accounts.

3.2.2 Condition account supplementary material

National approach

Data availabilty

For the nationally consistent approach, pre- and post-restoration extents for each ecosystem were combined to identify the mutually inclusive area (i.e. cells that were the same ecosystem type for both before and after restoration activities). This was necessary for some condition indicators to ensure pre- and post-restoration measurements of condition were meaningful. Condition indicators were then derived for each ecosystem type including age since restoration activities, vegetation cover, AGB, vegetation greenness, landscape wetness, and connectivity of ecosystem. All analyses were undertaken in the DEA sandbox (https://docs.dea.ga.gov.au/setup/Sandbox/sandbox.html), where all necessary data is freely available; however, could also be undertaken in a desktop GIS platform with data downloaded.

To derive condition indicators, additional datasets were used to complement the extent dataset, including:

- Age since restoration activities: Same as datasets used to detect ecosystem extents.
- Vegetation cover: Woody Vegetation Cover Fraction (http://wenfo.org/tree/).
- AGB: ESA CCI Biomass (https://climate.esa.int/en/projects/biomass/).
- Vegetation greenness: Annual Landsat Geomedians (https://cmi.ga.gov.au/data-products/dea/645/dea-geometric-median-and-median-absolute-deviation-landsat).
- Landscape wetness: Annual Landsat Geomedians (https://cmi.ga.gov.au/data-products/dea/645/dea-geometric-median-and-median-absolute-deviation-landsat).
- Connectivity of ecosystem: Ecosystem extent outputs for before and after restoration.

Methods

Many of the nationally consistent datasets are produced annually, or with the prospect of being annual in the near future. First, the nationally consistent approach to generating ecosystem extent datasets were used to define ecosystem type boundaries for pre- and post-restoration activities. Pre- and post-restoration extents for each ecosystem were combined to identify the mutually inclusive area (i.e. cells that were the same ecosystem type for both before and after restoration activities). This was necessary for some condition indicators to ensure both pre- and post-restoration activities measurements of condition were meaningful. Condition indicators were then derived for each ecosystem type including age since restoration activities, vegetation cover, AGB, vegetation greenness, landscape wetness, and connectivity of ecosystem. All analysis was undertaken in the DEA sandbox (https://docs.dea.ga.gov.au/setup/Sandbox/sandbox.html), where all necessary data is freely available, however could also be undertaken in a desktop GIS platform with data downloaded as per links above. Details of analysis steps for each condition indicator are described below.

Age since restoration activities

- Methods used to generate ecosystem extents were also undertaken for each year between pre- and post-restoration extents.
- Post-restoration extent was used to extract each annual extent of mangrove, saltmarsh, supratidal forests, waterbodies/mudflats, and other land covers.
- For each pixel, a sequential sum of the presence of the ecosystem across years was generated, whereby if the ecosystem was not present for a particular year, the sum was reset.
- A relative age of each pixel for the post-restoration dataset was generated for each ecosystem type.
- Age reported in years since restoration; there was no capacity to calculate pre-restoration age.

Vegetation cover

- Woody Vegetation Cover Fraction (WCF) was extracted for pre- and post-restoration years using the site boundary.
- The pre- and post-restoration mutually inclusive areas were used to extract WCF for mangrove, saltmarsh, supratidal forests, and other land covers.
- An increase in WCF for mangrove, supratidal forests, and other land covers was considered an increase in vegetation cover; however, a decrease in WCF was considered an increase in vegetation cover for saltmarsh (due to dominant species composition).
- Vegetation cover was scaled to indicate condition as a value between 0 (poor) and 1 (good).

Above-ground biomass

- AGB data was available for 2010 and 2018 and these were used as pre-(2007) and post-(2021) restoration years, respectively.
- The pre- and post-restoration mutually inclusive areas were used to extract AGB for mangrove, saltmarsh, supratidal forests, and other land covers.
- An increase in ecosystem condition was indicated where an increase in AGB (reported in Mg ha^{-1}) occurred.

Vegetation greenness

- Landsat Annual Geomedians were extracted for pre- and post-restoration datasets using the site boundary.
- Geomedians were used to calculate the Normalised Difference Vegetation Index (NDVI) using the red and near-infrared spectral bands of the Geomedians.
- The pre- and post-restoration mutually inclusive area was used to extract NDVI for mangrove, saltmarsh, supratidal forests, and other land covers.

- Vegetation greenness was reported as a condition indicator between 0 (poor) and 1 (good) by scaling NDVI values in a linear fashion.

Landscape wetness

- Landsat Annual Geomedians were extracted for pre- and post-restoration datasets using the site boundary.
- Geomedians were used to calculate the Modified Normalised Difference Wetness Index (MNDWI) using the green and short wave infrared spectral bands of the Geomedians.
- The pre- and post-restoration mutually inclusive areas were used to extract MNDWI for mangrove, saltmarsh, supratidal forests, waterbodies/mudflats, and other land covers.
- Landscape wetness was reported as a condition indicator between 0 (poor) and 1 (good) by scaling MNDWI values in a linear fashion.

Connectivity of ecosystem

- Pre- and post-restoration extents for each ecosystem type were used to generate an indicator for connectivity of each ecosystem type.
- For each pixel of the ecosystem type, the surrounding cells were used to provide a ratio of connectedness of the pixel (e.g. connectivity score of 0.125 (1/8) where pixel was only connected to 1 other pixel of same ecosystem type).
- Connectivity of an ecosystem was reported as a condition indicator between 0 (poor) and 1 (good) based on the ratio of connectivity for each pixel.

Multiple approaches were undertaken to report change in condition indicators. First, number of cells for each ecosystem type were totalled and averaged on the basis of extent. The mean value was input into the SEEA-EA tables (**Table 3.4**) where post-restoration was subtracted from pre-restoration to provide change in ecosystem condition for each indicator. Second, the direction of change of a cell value (i.e. positive = increase in condition, negative = decrease in condition) was identified and summed up to provide a total change in area (ha) of the condition indicator. Negative change in condition indicator area was subtracted from positive change in condition indicator area to provide net change area of positive or negative condition change and reported in SEEA-EA tables (**Table 3.5**).

Results

Spatial variation in age of each ecosystem is provided in **Figures 3.3 - 3.5**. Pre- and post-restoration changes in vegetation cover, above-ground biomass vegetation greenness and landscape wetness are provided in **Figures 3.6 - 3.9**. Supratidal forest cover and greenness increased post-restoration; however, decreases in vegetation cover and greenness for saltmarsh were detected. Many indicators demonstrated substantial spatial variability for coastal wetland ecosystems both pre- and post-restoration activities; hence generalising trends was challenging. Restoration activities demonstrated an increase in connectivity of coastal ecosystems, with a decrease in connectivity of other land covers. An increase in saltmarsh AGB was detected, while other ecosystems remained constant (**Figures 3.10 - 3.14**)

Table 3.3: Ecosystem condition indicator account for restoration project at Tomago in 2007 and 2021[14] using National approach data. *Continued over page.*

SEEA Ecosystem Condition Typology Class			Indicators				
			Descriptor	Measurement unit	Opening value	Closing value	Change in indicator
Mangrove	Abiotic		Landscape wetness	Spectral index, rescaled (0-1)	0.26 (0.01)	0.28 (0.01)	0.02
	Biotic	Structural state	Age since restoration activities	Years	-	16.93	0
			Vegetation cover	% cover, rescaled (0-1)	0.59 (0.04)	0.58 (0.05)	0.05
			Above-ground biomass	Mg ha^{-1}	60.32 (27.06)	60.45 (22.09)	0.13
		Functional state	Vegetation greenness	Spectral index, rescaled (0-1)	0.85 (0.02)	0.85 (0.02)	0
	Landscape/seascape characteristics		Connectivity of ecosystem	Index, rescaled (0-1)	0.23 (0.11)	0.23 (0.11)	0
Saltmarsh	Abiotic		Landscape wetness	Spectral index, rescaled (0-1)	0.22 (0.01)	0.23 (0.04)	0.01
	Biotic	Structural state	Age since restoration activities	Years	-	10.21 (3.96)	-
			Vegetation cover	% cover, rescaled (0-1)	0.7 (0.07)	0.6 (0.09)	-0.1
			Above-ground biomass	Mg ha^{-1}	7.57 (14.9)	3 (9.49)	-4.57
		Functional state	Vegetation greenness	Spectral index, rescaled (0-1)	0.79 (0.03)	0.77 (0.03)	-0.02
	Landscape/seascape characteristics		Connectivity of ecosystem	Index, rescaled (0-1)	0.51 (0.31)	0.54 (0.3)	0.03
Supratidal forests	Abiotic		Landscape wetness	Spectral index, rescaled (0-1)	0.25 (0.01)	0.28 (0.04)	0.03
	Biotic	Structural state	Age since restoration activities	Years	-	9.88 (5.12)	-
			Vegetation cover	% cover, rescaled (0-1)	0.59 (0.05)	0.67 (0.05)	0.08
			Above-ground biomass	Mg ha^{-1}	56.42 (32.34)	54.75 (27.09)	-1.67
		Functional state	Vegetation greenness	Spectral index, rescaled (0-1)	0.86 (0.01)	0.88 (0.01)	0.02
	Landscape/seascape characteristics		Connectivity of ecosystem	Index, rescaled (0-1)	0.47 (0.29)	0.52 (0.32)	0.05

[14] Opening account year = 2005, closing account year = 2021). Values are mean of all cells in restoration activity boundary, values brackets indicate standard deviation. Comparison area for opening and closing mean values is the mutually inclusive area of the ecosystem type (i.e. where mangrove was present in both pre- and post-restoration activities).
*unreliable estimates from datasets and not included

Table 3.3: Cont.

SEEA Ecosystem Condition Typology Class			Indicators				
			Descriptor	Measurement unit	Opening value	Closing value	Change in indicator
Waterbodies/ muddflats	Abiotic		Landscape wetness	Spectral index, rescaled (0-1)	-	-	-
	Biotic	Structural state	Age since restoration activities	Years	-	6.82 (2)	-
			Vegetation cover	% cover, rescaled (0-1)	-	-	-
			Above-ground biomass	Mg ha^{-1}	-	-	-
		Functional state	Vegetation greenness	Spectral index, rescaled (0-1)	-	-	-
	Landscape/seascape characteristics		Connectivity of ecosystem	Index, rescaled (0-1)	0	0.5 (0.31)	0.5
Other land covers	Abiotic		Landscape wetness	Spectral index, rescaled (0-1)	0.23 (0.02)	0.25 (0.02)	0.02
	Biotic	Structural state	Age since restoration activities	Years	-	15.73 (1.24)	-
			Vegetation cover	% cover, rescaled (0-1)	0.35 (0.13)	0.47 (0.15)	0.12
			Above-ground biomass	Mg ha^{-1}	13.23 (20.02)	9.69 (19.3)	-3.54
		Functional state	Vegetation greenness	Spectral index, rescaled (0-1)	0.81 (0.03)	0.83 (0.04)	0.02
	Landscape/seascape characteristics		Connectivity of ecosystem	Index, rescaled (0-1)	0.59 (0.31)	0.41 (0.26)	-0.18

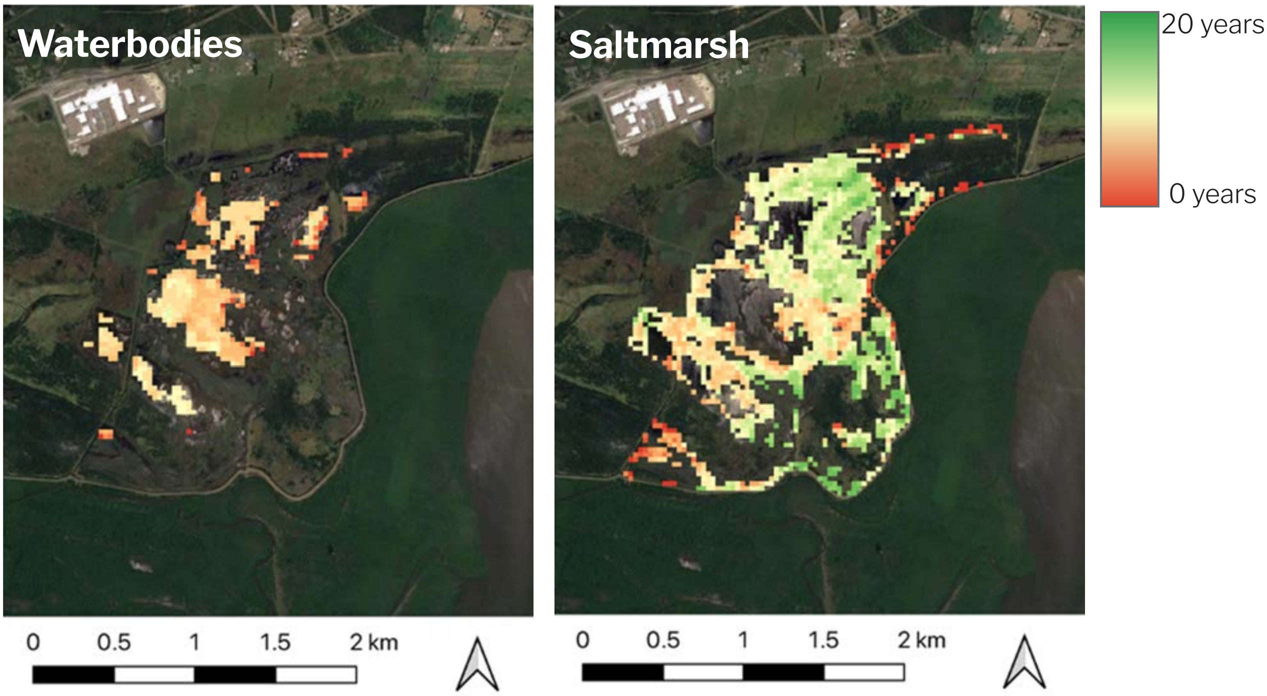

Figure 3.3: Waterbodies/Mudflats (left), and saltmarsh (right) age since restoration activities at Tomago using National Approach data.

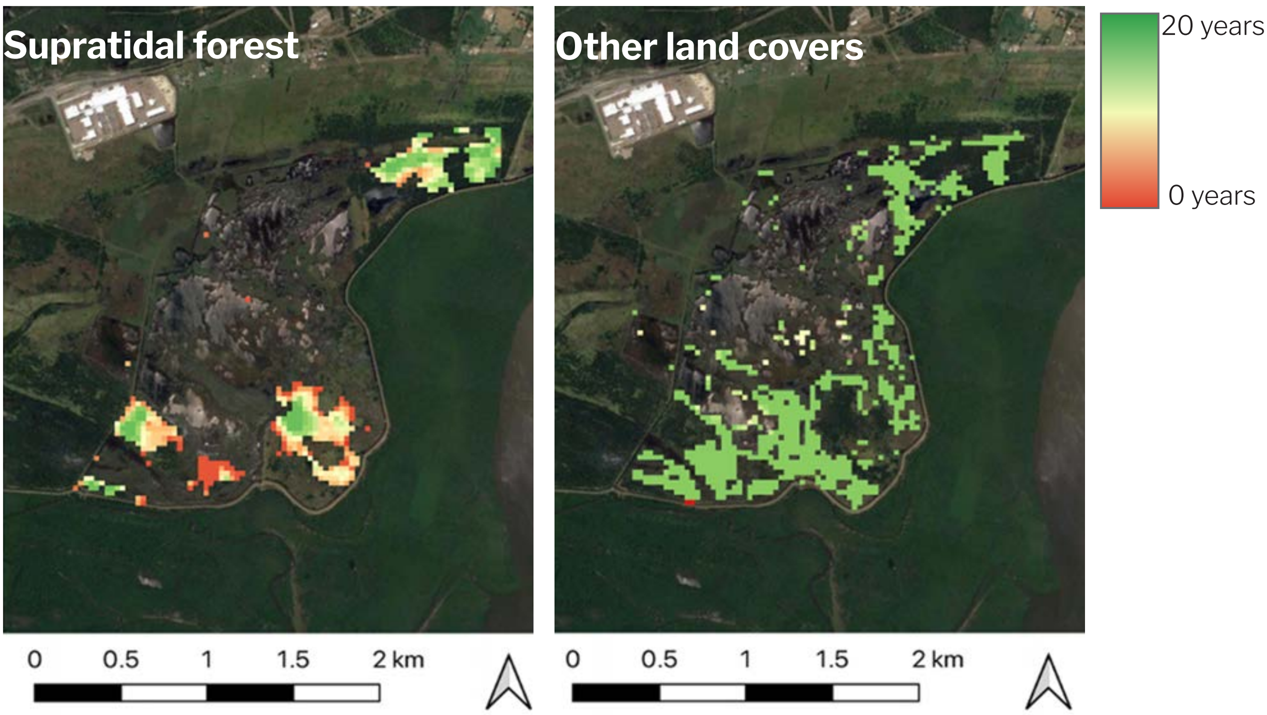

Figure 3.4: Supratidal forest (left) and other land covers (right) age since restoration activities at Tomago using National Approach data.

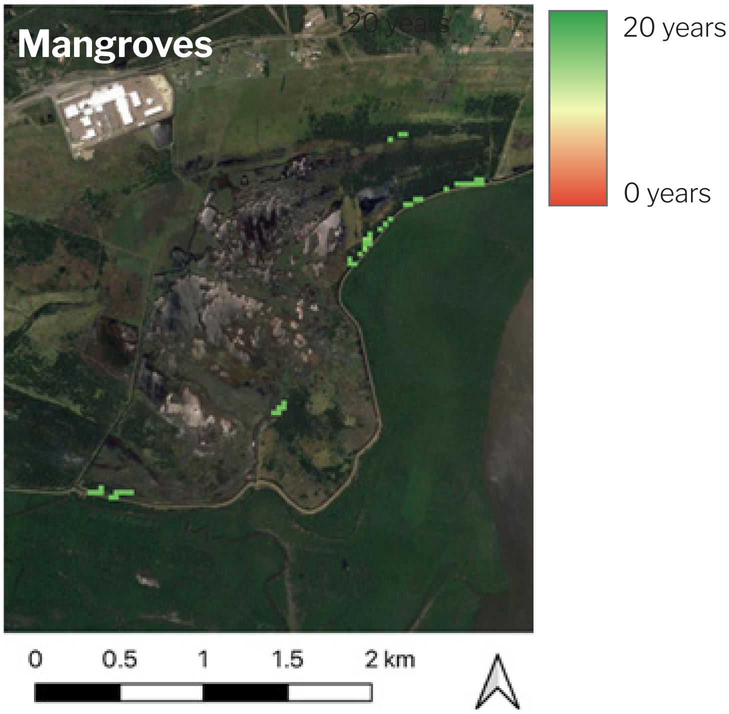

Figure 3.5: Mangrove age since restoration activities at Tomago using National Approach data.

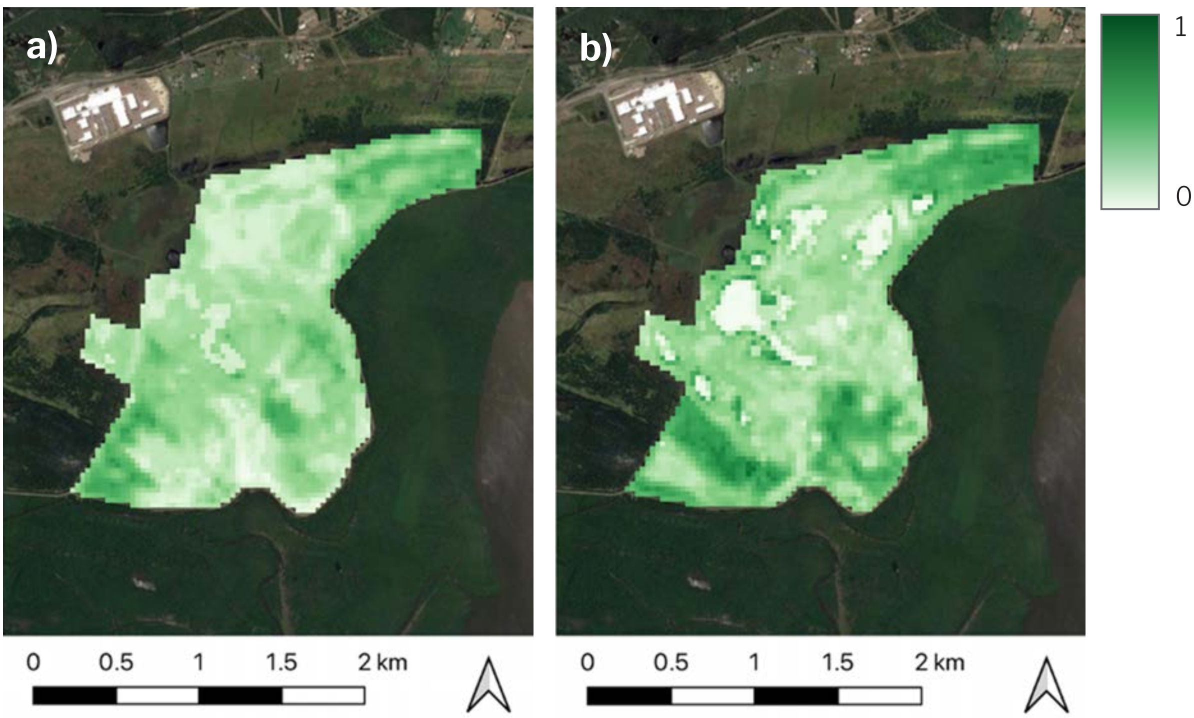

Figure 3.6: Vegetation cover a) before (~2005) and b) after (~2021) restoration activities at Tomago using National Approach data.

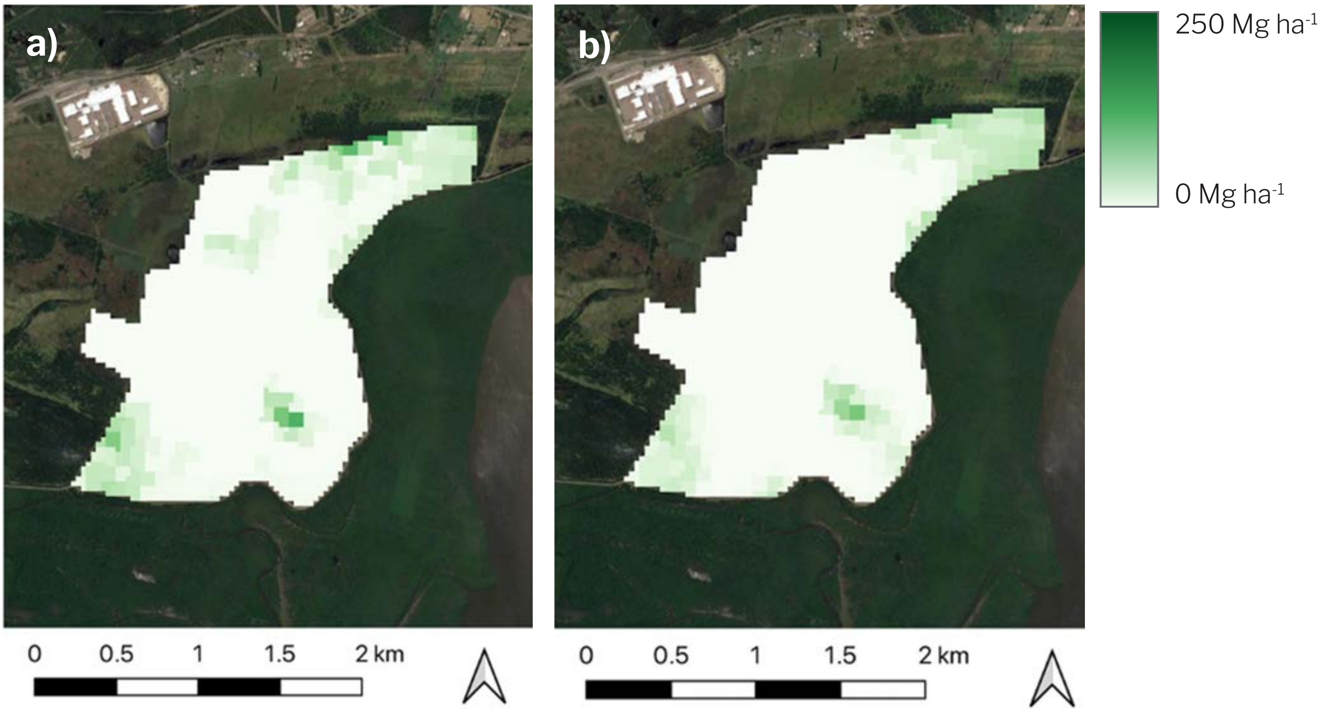

Figure 3.7: Above-ground biomass a) before (~2010) and b) after (~2018) restoration activities at Tomago using National Approach data.

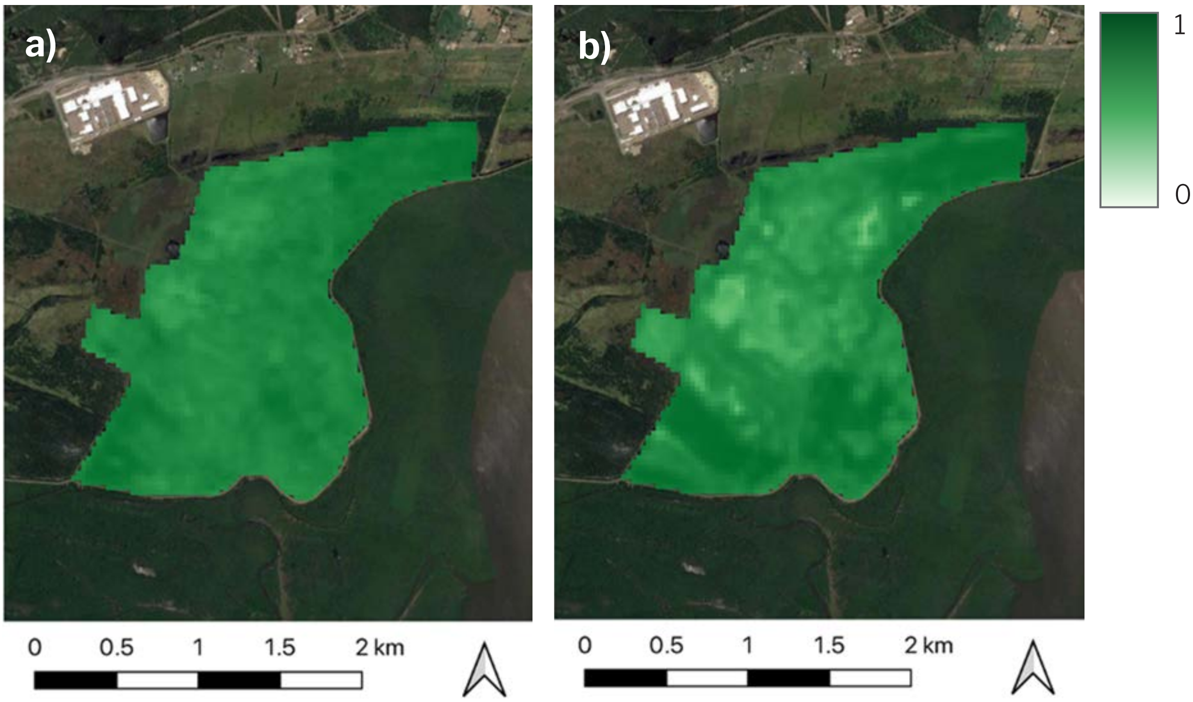

Figure 3.8: Vegetation greenness a) before (~2005) and b) after (~2021) restoration activities at Tomago using National Approach data.

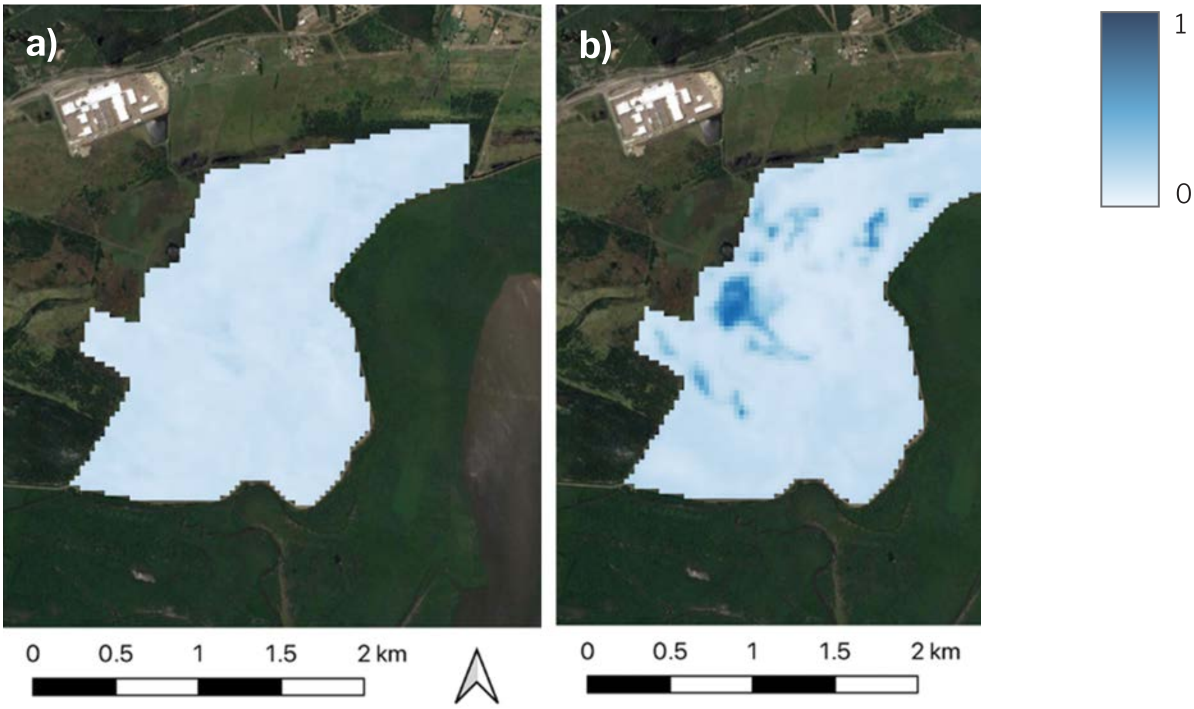

Figure 3.9: Landscape wetness a) before (~2005) and b) after (~2021) restoration activities at Tomago using National Approach data.

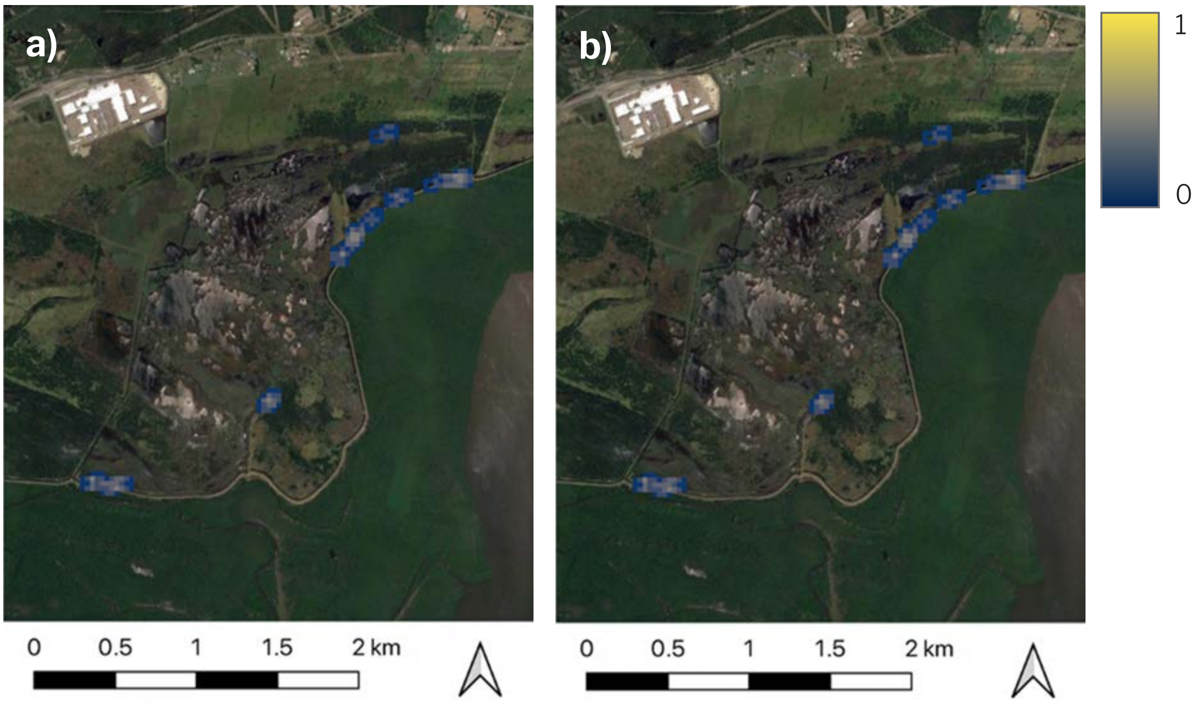

Figure 3.10: Mangrove ecosystem connectivity a) before (~2005) and b) after (~2021) restoration activities at Tomago using National Approach data.

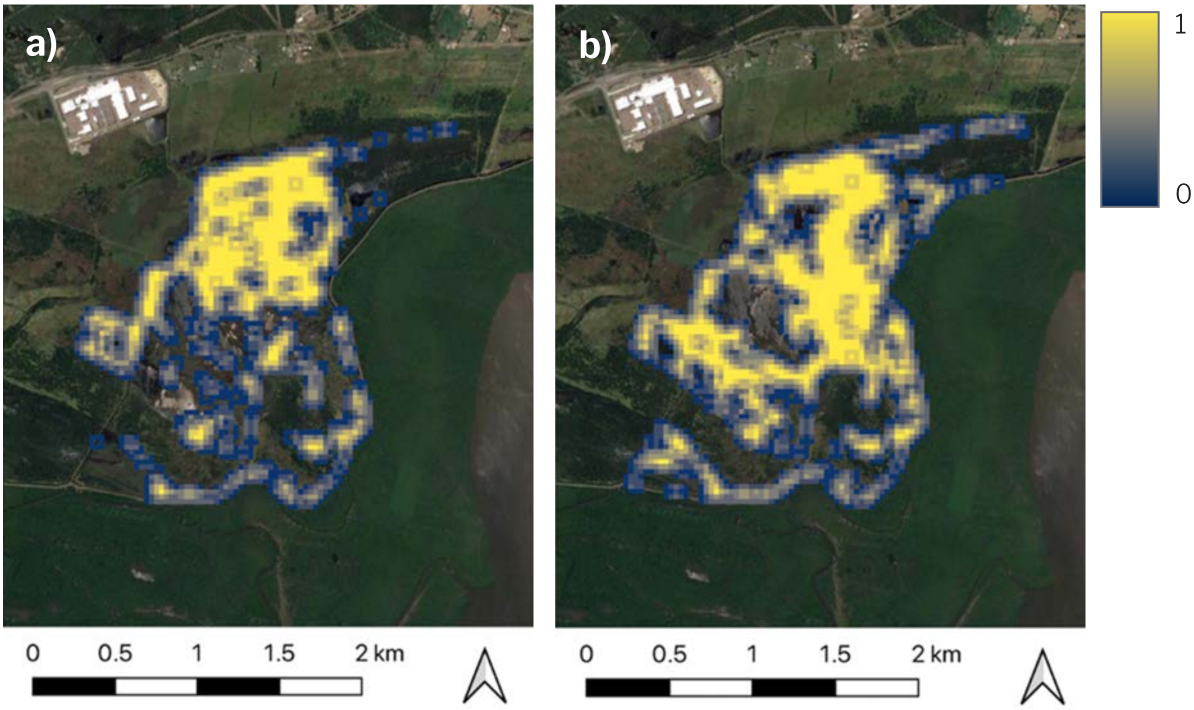

Figure 3.11: Saltmarsh ecosystem connectivity a) before (~2005) and b) after (~2021) restoration activities at Tomago using National Approach data.

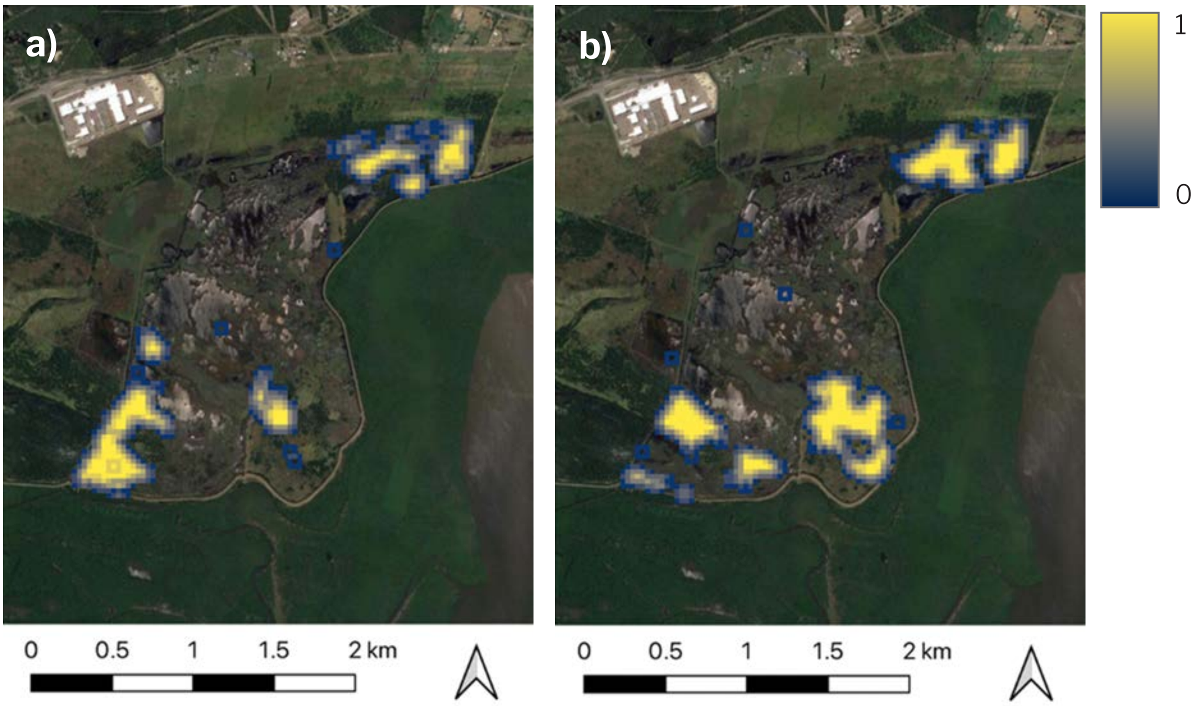

Figure 3.12: Supratidal forest ecosystem connectivity a) before (~2005) and b) after (~2021) restoration activities at Tomago using National Approach data.

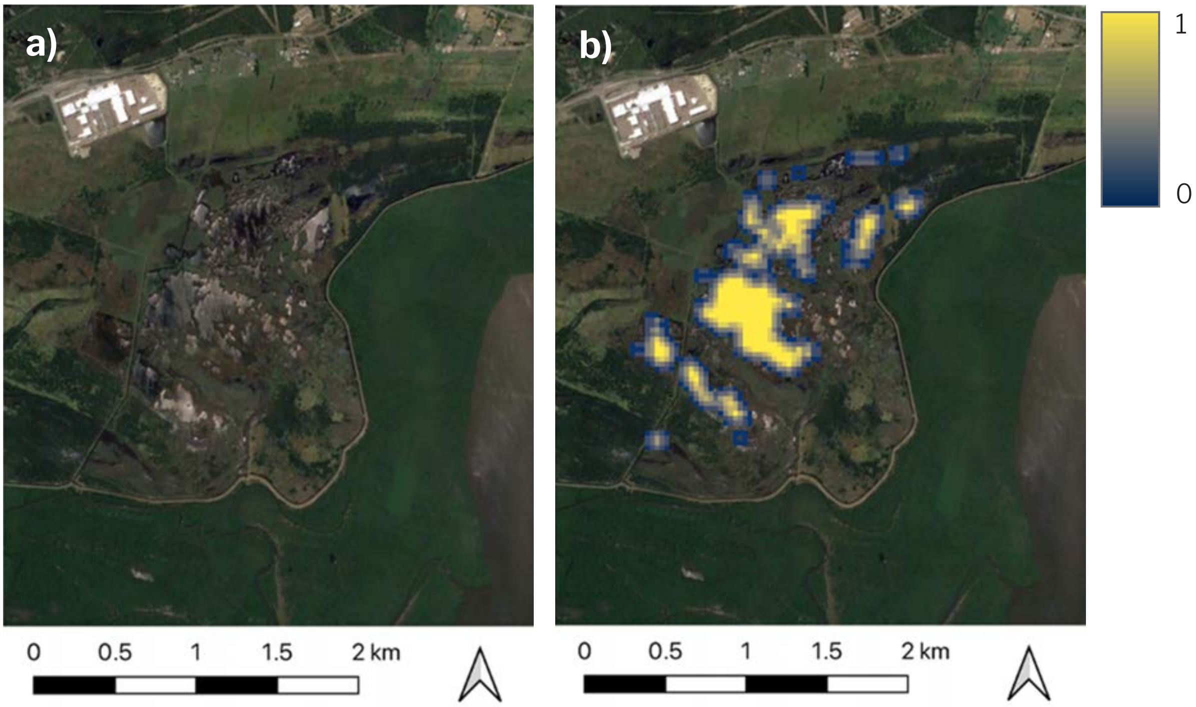

Figure 3.13: Waterbodies/mudflats connectivity a) before (~2005) and b) after (~2021) restoration activities at Tomago using National Approach data.

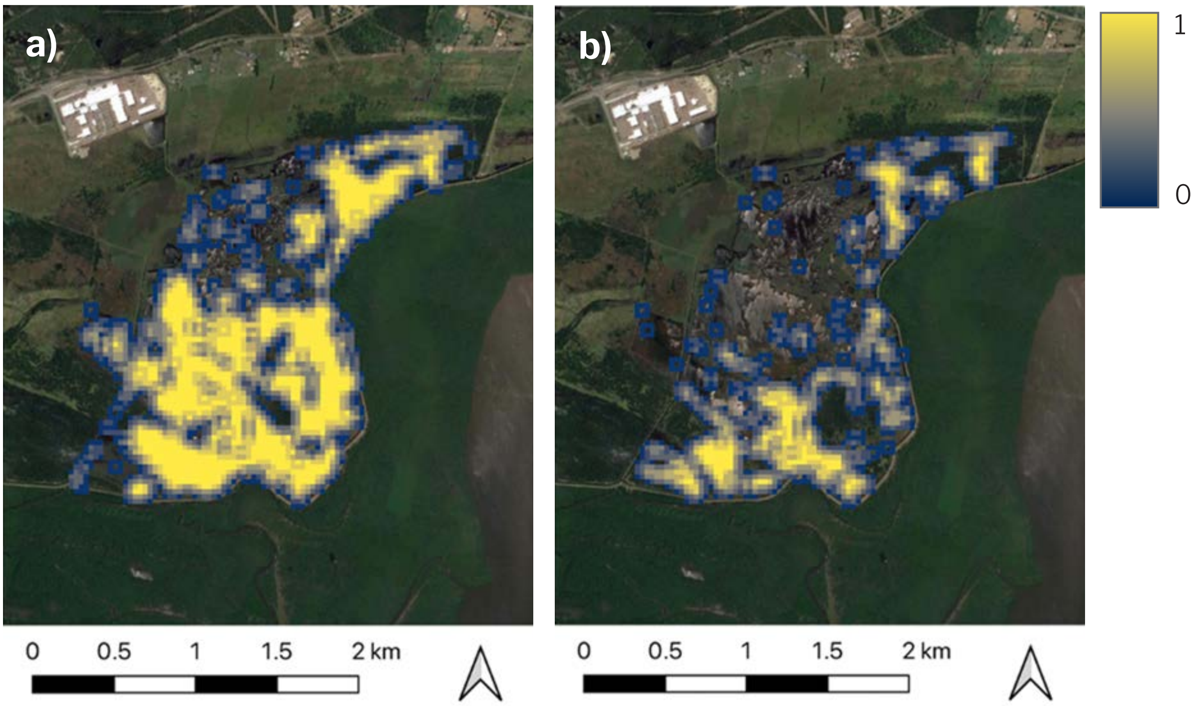

Figure 3.14: Other land covers connectivity a) before (~2005) and b) after (~2021) restoration activities at Tomago using National Approach data.

Interpretation and discussion

The overall capacity to assess condition at the national scale was dependent upon access to the best data available without being designed for this intent from the beginning, and that condition could be assessed using consistent methods. There are, however, a range of other indicators that could be used to assess the structure, function and composition of an ecosystem, providing sufficient data was available. This could be resolved in future assessments when data availability improves.

It was critical that the condition of saltmarsh over time was based on assessing saltmarsh in areas that were always saltmarsh, not areas that were not saltmarsh prior to the restoration activity. This meant that condition was assessed in mutually inclusive areas at the opening and closing data as a priority, and these condition changes were used to ascertain whether the areas that had changed extent had also improved in condition.

To overcome some of these issues while ensuring comparisons were made between the same areas, we developed an approach that allowed us to report on the extent of area that either improved or declined in condition. We advocate this as the best approach for reporting changes in condition, rather than reductive approaches that rely on changes in mean values of indicators over time.

It is also worthwhile emphasising that a condition indicator can be used to establish differences in condition between ecosystems, or over time, however a step change in condition between indicators is not an appropriate comparison, and should not be undertaken. For example, NDVI changes can be compared between ecosystems, or over time, but should not be compared to indicators of landscape greenness.

As with other assessments, access to data was limited, and this meant that AGB could only be determined during 2010 and 2018, and the reporting values did not align perfectly with the opening and closing periods for the SEEA-EA tables. This approach is only utilised here due to relying on existing datasets. Measurements within the reporting period are the preferred method as outlined in the Guide.

Detailed approach

Data availabilty

For the high accuracy assessments there are few publicly available and existing spatial or field datasets for Tomago that can be used to develop fine scale indicators of condition (i.e. canopy cover, species richness and connectivity, across biotic and abiotic parts of the system). However, some datasets were available that could be used with the extent mapping to develop condition indicators for pre- and post-restoration condition assessment, including:

- Canopy height models (CHMs) derived from LiDAR data (https://elevation.fsdf.org.au/). Areas of high condition would likely be associated with tall mature forest and newly established colonising zones indicating favourable conditions.
- Connectivity of ecosystem: Ecosystem extent outputs for pre- and post-restoration derived from the national approach.
- Age since restoration activities: Ecosystem extent outputs for pre- and post-restoration derived from the national approach.
- AGB: derived using the BlueCam method.
- CCI biomass: 2018 map of above-ground biomass (AGB, Mg ha^{-1}).

Methods

The detailed approach to condition is limited the availability of high-resolution datasets, particularly pre-restoration. The approach used the detailed extent mapping in ArcMap to understand changes in land cover pre- and post-restoration and applied indicators were suitable. Firstly, the detailed approach to generating ecosystem extent datasets was used to define land cover change for pre- and post- restoration activities. This was derived by comparing the pre- and post-restoration extents using Spatial Analyst (Erase) and Geoprocessing tools (Clip and Intersect) in ArcMap. The Calculate Geometry tool was used to calculate the area of land cover pre- and post-restoration to identify stable areas (i.e. no change in land cover) and the area of each conversion type (i.e. grass to saltmarsh).

The spatial datasets were colour coded using a traffic light system to indicate where changes aligned with the aim of the restoration activities. For example, areas that changed from grassland to saltmarsh achieved the aim of the restoration project and were mapped as green, as opposed to areas that changed to grass which appear as red. Changes to supratidal forest or mudflats/ponds were coloured orange as this represents a positive change in the environment (i.e. returning to a wetland system), yet not the aim of the restoration.

Condition indicators were then derived for each ecosystem type and land cover change, where suitable, including above-ground biomass derived from Blue Cam, connectivity of ecosystem and productivity measures: vertical growth per year and AGB gain per year. Age and connectivity analysis was undertaken in the DEA sandbox (https://docs.dea.ga.gov.au/setup/Sandbox/sandbox.html), where all necessary data is freely available, however could also be undertaken in a desktop GIS platform with data downloaded as per links above. Spatial analysis of AGB and productivity measures was conducted in ArcMap. Details of analysis steps for each condition indicator are described below:

- AGB measurements for each ecosystem class, calculated using BlueCAM and presented in **Section 4.4.1**, were used to indicate changing ecosystem condition.
- The difference in AGB was calculated by subtracting post-restoration AGB from pre-restoration AGB. Significant changes in AGB (i.e. a loss or gain greater than 10 t DW ha^{-1}), coloured red or green respectively. A small difference in AGB (i.e. a difference less than 10 t DW ha^{-1}) was recorded as negligible change and coloured orange.

Connectivity of ecosystem (derived from national approach)

- Pre- and post-restoration extents for each ecosystem type were used to generate an indicator for connectivity of each ecosystem type.
- For each pixel within an ecosystem type, the surrounding cells were used to provide a ratio of connectedness of the pixel (e.g. connectivity score of 0.125 (1/8) where pixel was only connected to 1 other pixel of same ecosystem type).

- Connectivity of an ecosystem was reported as a condition indicator between 0 and 1 based on ratio of connectivity for each pixel.

Age since restoration activities was required for productivity estimates; the age was derived from national approach:

- Methods used to generate ecosystem extents also undertaken for each year between pre- and post-restoration extents.
- Post-restoration extent was used to extract each annual extent of mangrove, saltmarsh, supratidal forests, waterbodies/mudflats, and other land covers.
- For each pixel, a sequential sum of the presence of the ecosystem was generated, whereby if the ecosystem was not present for a particular year, the sequential sum was reset.
- A relative age of each pixel for the post-restoration dataset was generated for each ecosystem type.
- Age was reported in years since restoration, with no capacity to calculate pre-restoration age.

Productivity: vertical growth per year for supratidal forests was determined as follows:

- Canopy height model (CHM) was generated using 2014 LiDAR point cloud data (derived from https://elevation.fsdf.org.au/) using ArcMap.
- Using the Raster Calculator tool, the CHM was divided by the Age raster layer.
- A height per year value was derived per pixel for the post restoration dataset. A mean value was calculated for reporting purposes.

Productivity was indicated used AGB derived from CCI Biomass per year for supratidal forests, saltmarsh and other land covers according to the following approach:

- AGB derived from CCI Biomass in 2018 was used to indicate post-restoration biomass.
- Using the Raster Calculator tool, the AGB raster was divided by the Age raster.
- AGB additions per year (kg m^{-2} y^{-1}) was derived for each pixel in the post-restoration dataset. A mean value was calculated for reporting purposes.

Results

For the detailed approach restoration activities resulted in a significant increase in the extent of saltmarsh and a reduction in the area of dry scrub and grassland. Considering the aim of the restoration project was to convert drained grassland used for agriculture to saltmarsh for waterbird habitat, the change in land cover was colour coded according to a traffic light system. **Figure 3.15** demonstrates large areas of saltmarsh post-restoration coloured in green.

Similarly, a traffic light system was used to indicate areas of significant loss, significant gain and negligible change in AGB stocks for each land cover change (**Figure 3.16**). The values are presented in **Table 3.4**, with significant gains in AGB attributed to land cover change from grassland and dry scrub to supratidal forest. Significant losses of AGB were noted for conversion of supratidal forest to saltmarsh, grass and mudflats and ponds and as such are coloured red in **Figure 3.16**, as opposed to areas of significant gain in green and negligible change in orange.

Connectivity showed no remarkable change between pre- and post-restoration (**Table 3.5**, **Figures 3.17 - 3.21**), likely due to the different land cover classes pre- and post-restoration. Productivity measurements were only possible for select land cover classes due to the suitability of the data. For supratidal forests the canopy height model derived from 2014 LiDAR data was used with the age of the forest, to produce a mean of increase in height of 0.508 m yr^{1} (**Figure 3.22**, **Table 3.6**). Spatial variation in AGB per year indicated the highest rates of addition for saltmarsh, compared to supratidal forest and other land covers (**Figure 3.23**, **Table 3.6**). This value should be used with caution as it is likely an overestimation due to the age of the habitat.

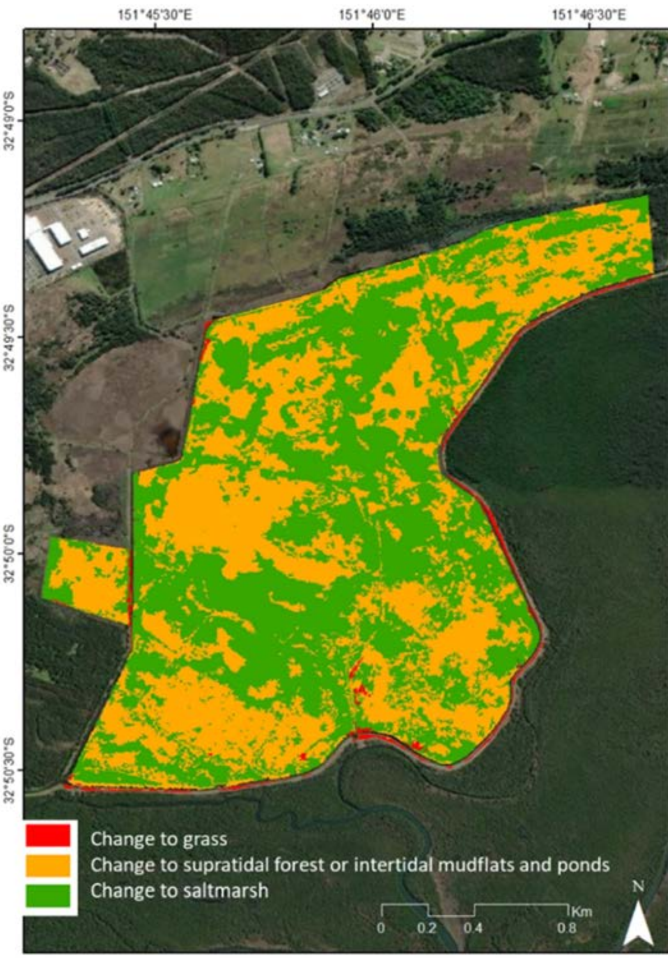

Figure 3.15: Change in landcover between pre- (~2007) and post-restoration (~2021) using the detailed approach. Areas of positive change (i.e. meet the aim of the restoration project) are coloured green. Areas in red are grassland, and areas of supratidal forest or mudflats/ponds were coloured orange as this represents a positive change in the environment (i.e. returning to a wetland system), yet not the aim of the restoration.

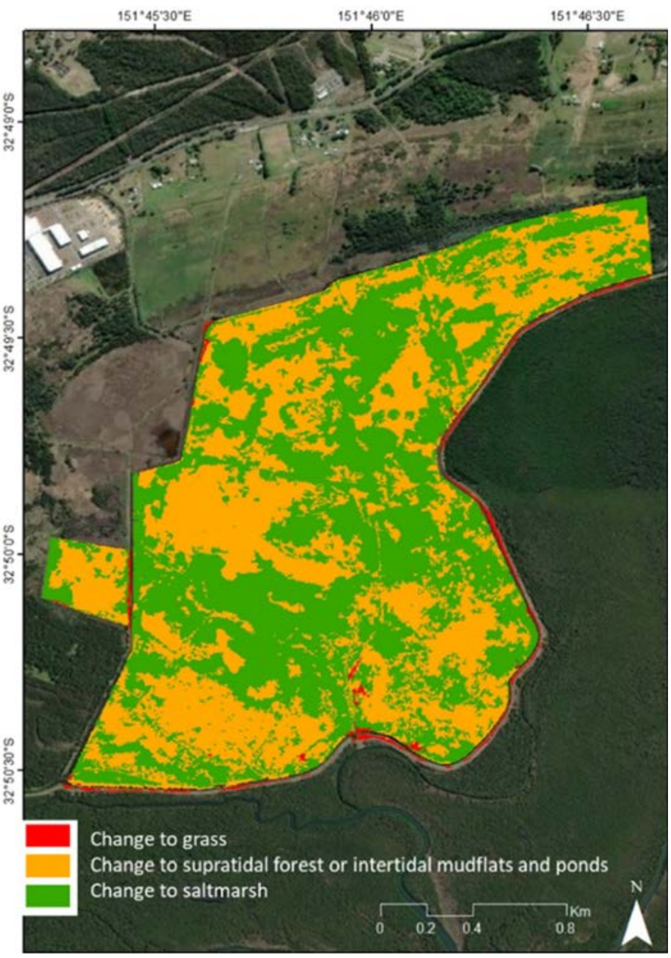

Figure 3.16: Post- restoration (~2021) representation of significant loss (red), gain (green) and negligible change (orange) in AGB derived from Blue Cam using the detailed approach.

Table 3.4: Change in land cover type, area and associated vegetation biomass stocks (above-ground biomass, AGB) derived from Blue Cam using the detailed approach. The difference in AGB indicates significant gain (blue), loss (red) and negligible change (orange).

Pre- restoration Land cover	Post- restoration Land cover	Area (ha)	Pre- restoration Vegetation biomass stocks – baseline AGB t DW ha^{-1}	Post- restoration Vegetation biomass stocks – baseline AGB t DW ha^{-1}	Difference in AGB
Supratidal forest	Supratidal forest	20.69	200.00	242.40	42.40
Supratidal forest	Saltmarsh	7.94	200.00	122.70	-77.30
Supratidal forest	Grass	0.06	200.00	120.00	-80.00
Supratidal forest	Mudflats and ponds	1.06	200.00	120.00	-80.00
Grass	Grass	2.73	10.50	6.30	-4.20
Grass	Mudflats and ponds	23.59	10.50	6.30	-4.20
Grass	Saltmarsh	52.81	10.50	9.00	-1.50
Grass	Supratidal forest	31.38	10.50	37.70	27.20
Dry scrub or cleared land	Grass	0.50	10.50	6.30	-4.20
Dry scrub or cleared land	Mudflats and ponds	38.28	10.50	6.30	-4.20
Dry scrub or cleared land	Saltmarsh	80.06	10.50	9.00	-1.50
Dry scrub or cleared land	Supratidal forest	34.35	10.50	37.70	27.20

Table 3.5: Connectivity before and after restoration activities using the detailed approach.

Mean connectivity (0-1)	Pre-restoration (~2005)	Class 1 (dry scrub or cleared land)	0.78
		Class 2 (grass)	0.70
		Class 3 (supratidal forests)	0.56
		Class 4 (waterbodies)	0.43
	Post-restoration (~2021)	Class 1 (grass)	0.74
		Class 2 (mudflats and ponds)	0.34
		Class 3 (saltmarsh)	0.75
		Class 4 (supratidal forests)	0.38
		Class 5 (waterbodies)	0.72

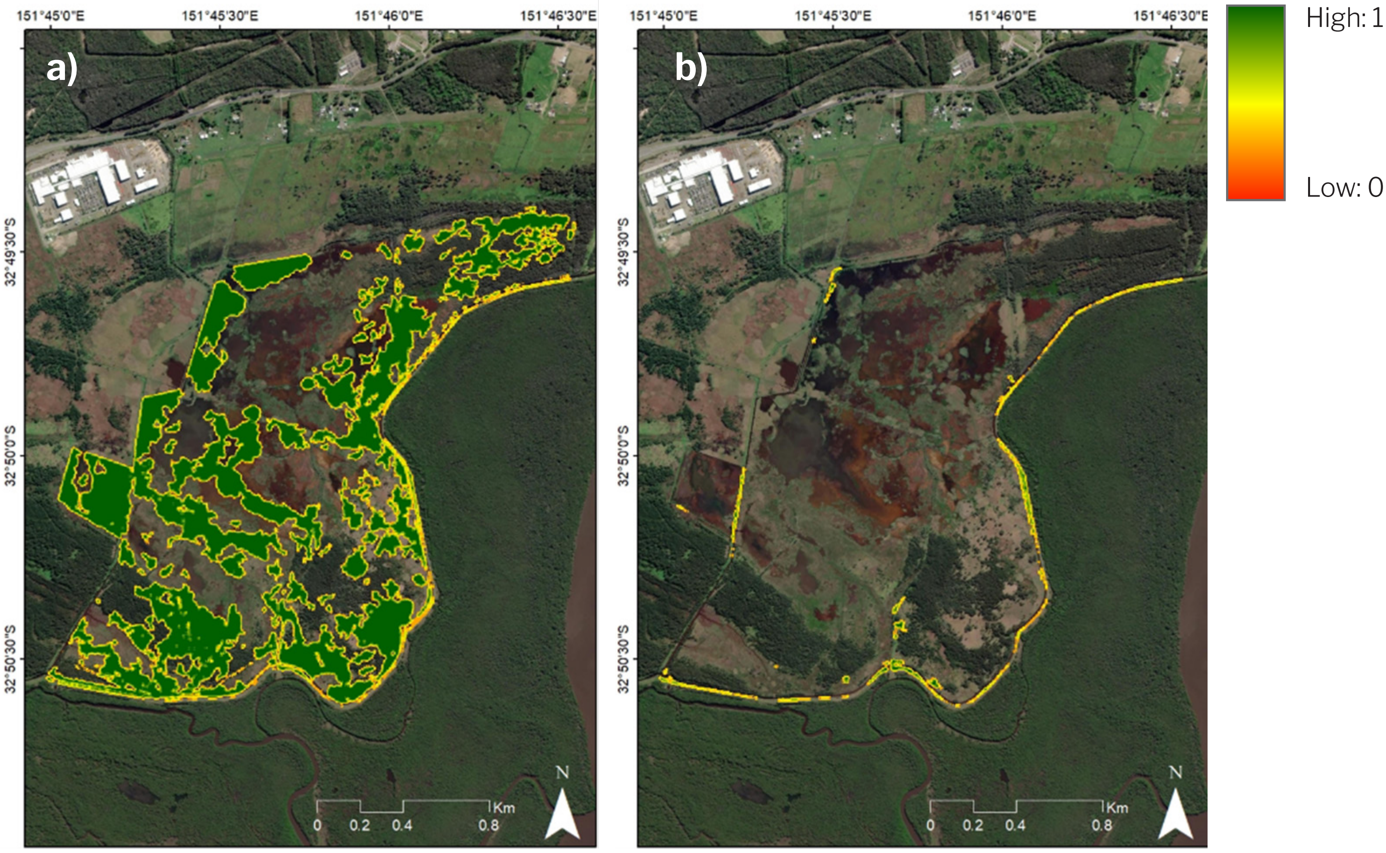

Figure 3.17: Grass connectivity a) pre- (~2005) and b) post-restoration (~2021) using the detailed approach.

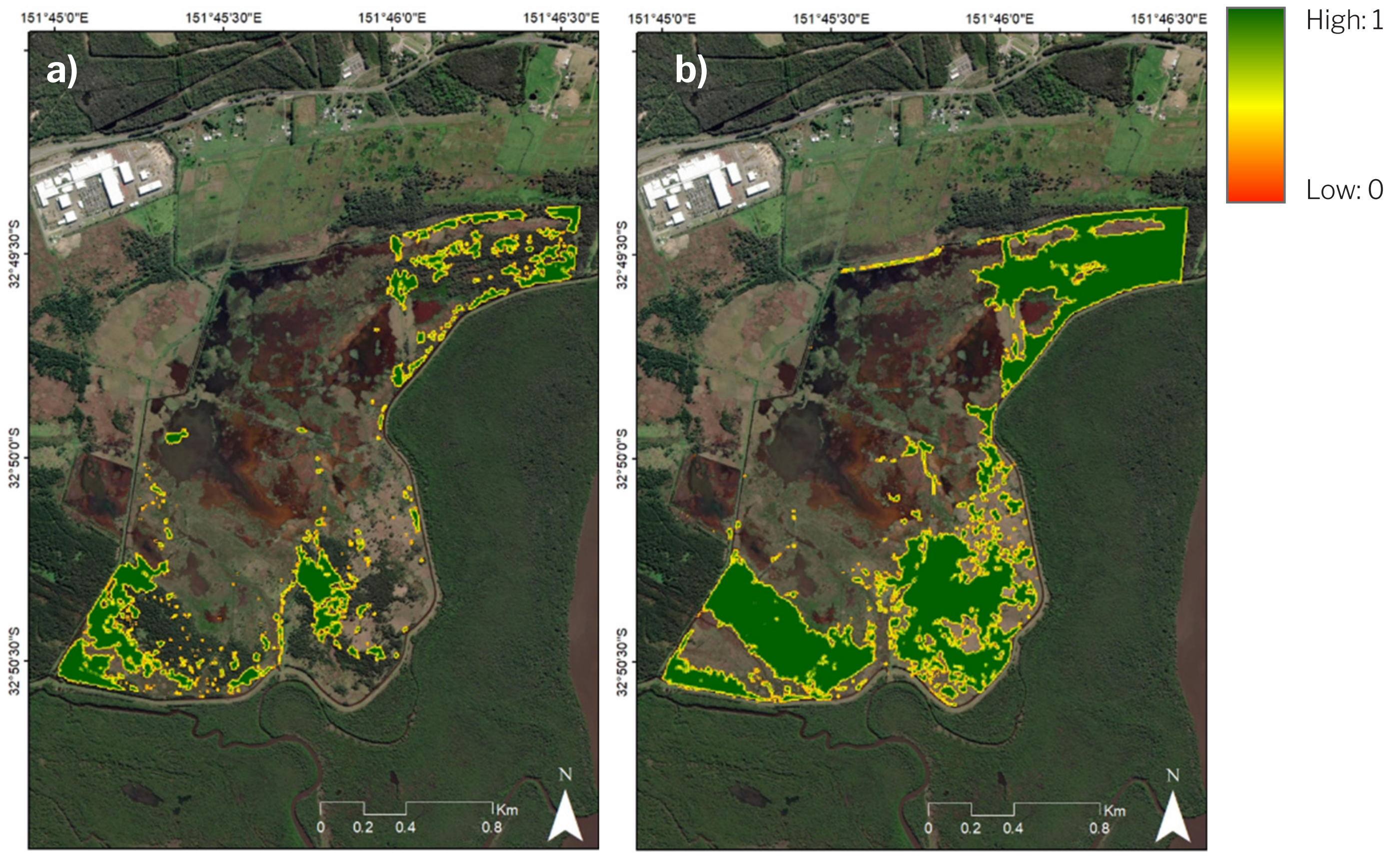

Figure 3.18: Supratidal Forest connectivity a) pre- (~2005) and b) post-restoration (~2021) using the detailed approach.

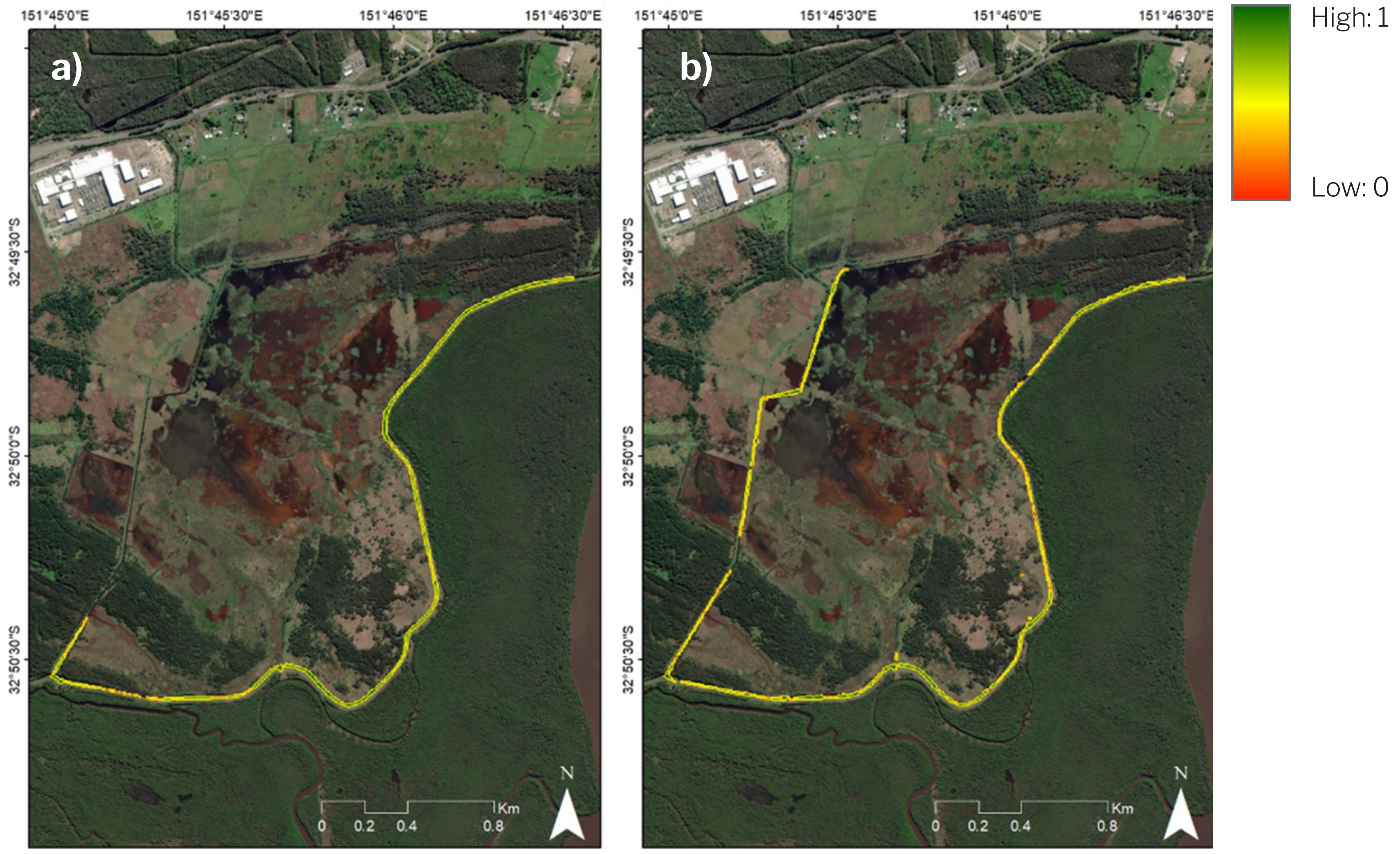

Figure 3.19: 'Waterbodies' connectivity a) pre- (~2005) and b) post-restoration (~2021) using the detailed approach.

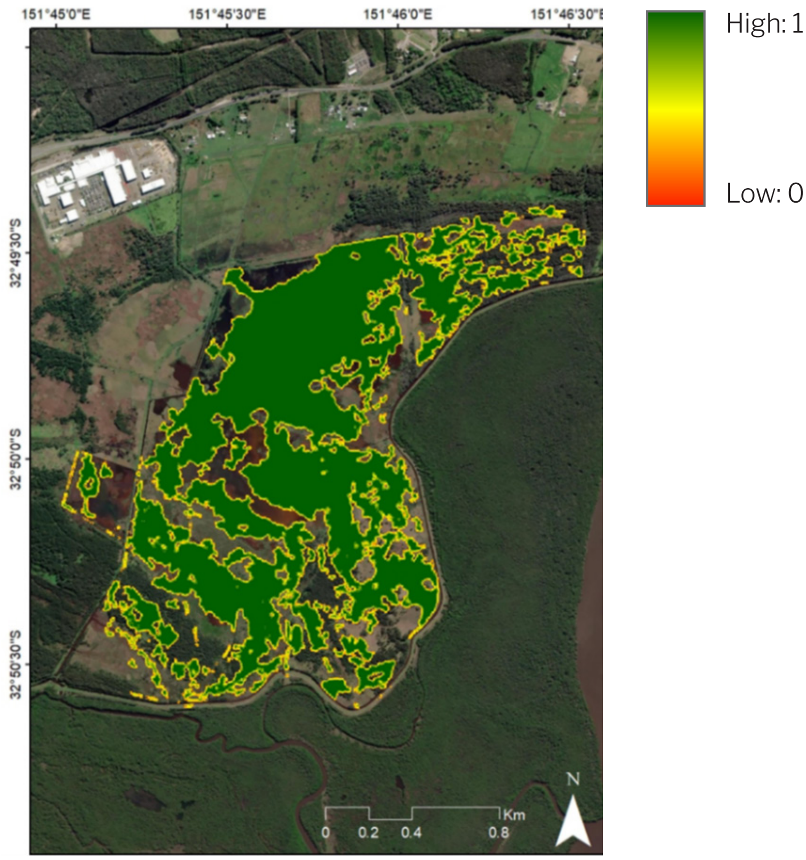

Figure 3.20: Dry scrub or cleared land connectivity pre-restoration (~2005) using the detailed approach.

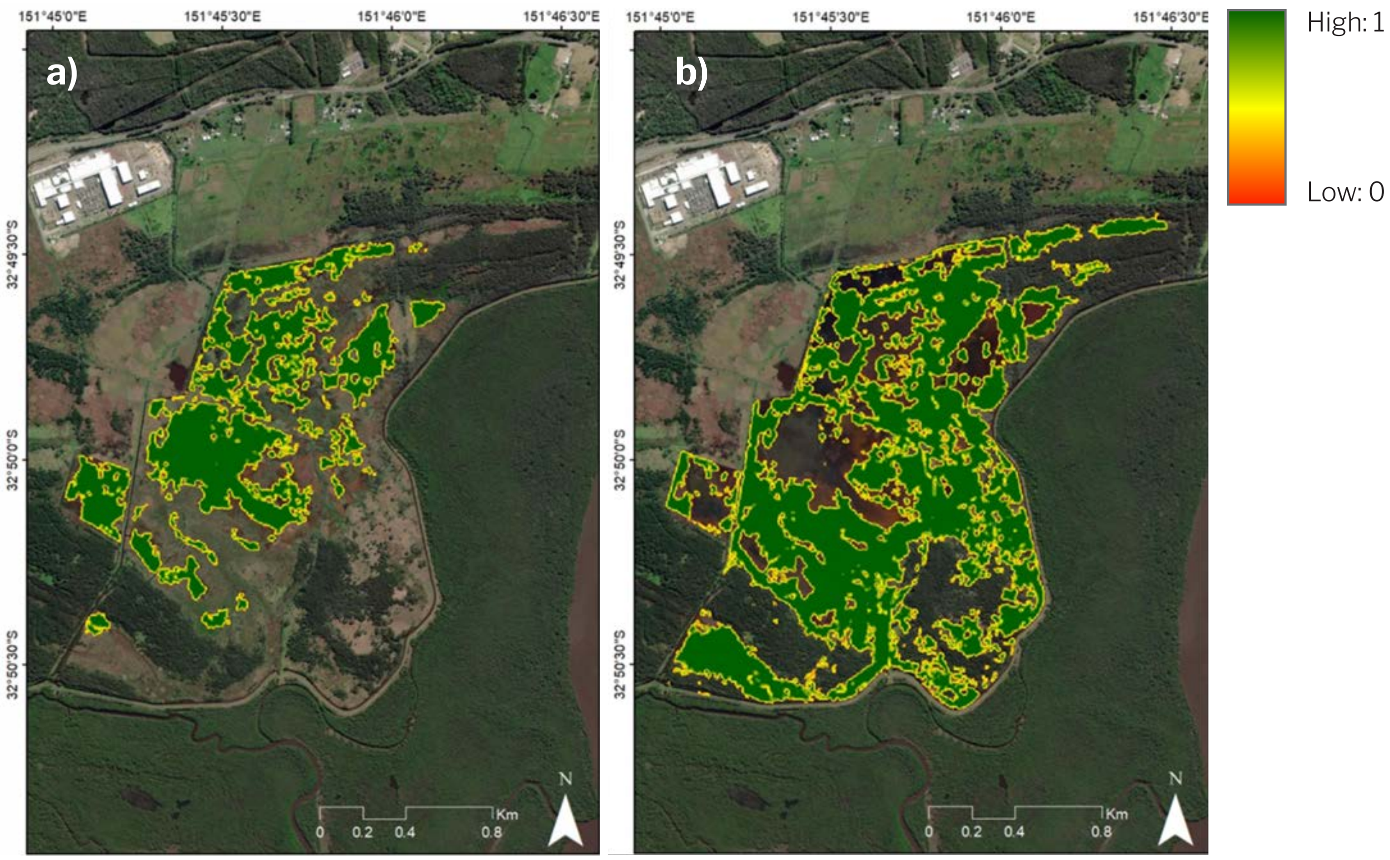

Figure 3.21: Mudflat/pond (left) and saltmarsh (right) connectivity post-restoration (~2021) using the detailed approach.

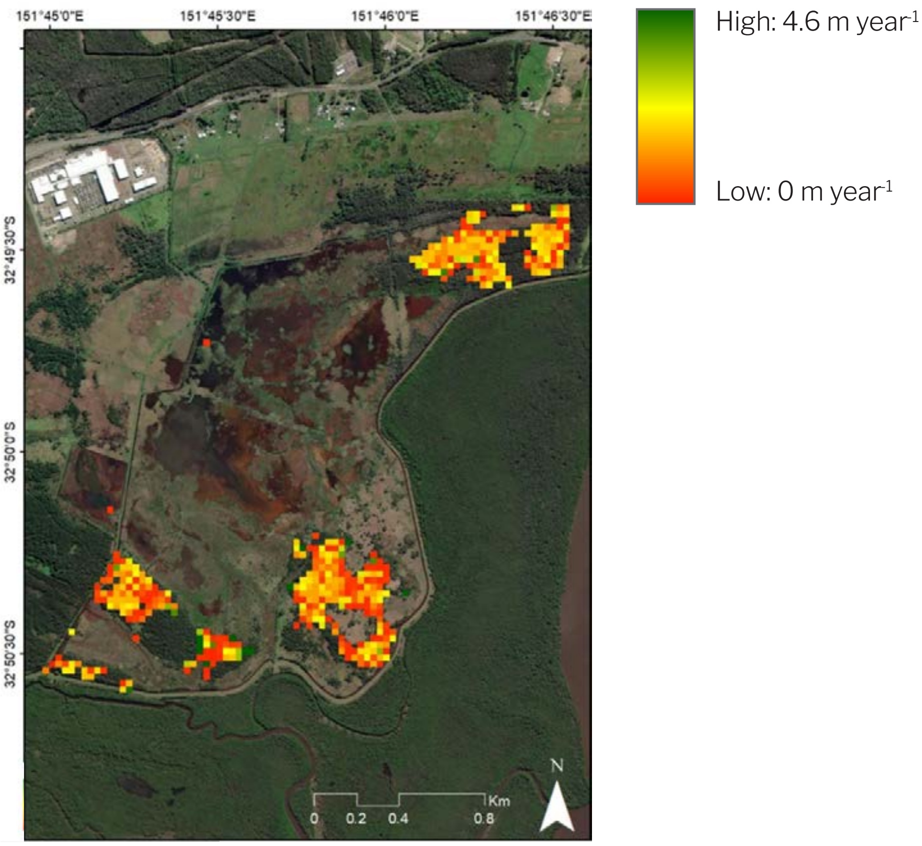

Figure 3.22: Vertical growth (i.e. height) per year for supratidal forests (post-restoration ~2021) using the detailed approach.

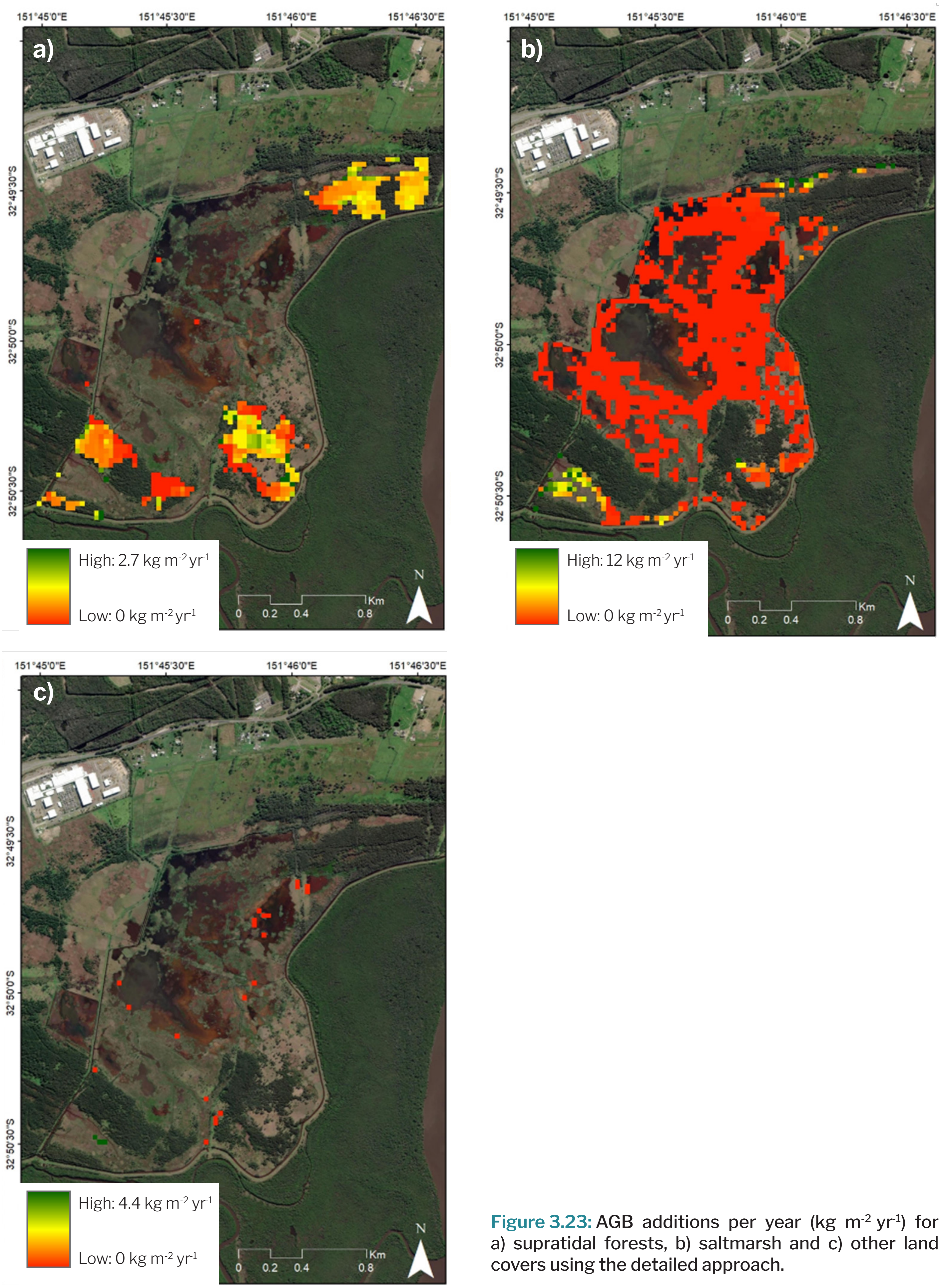

Figure 3.23: AGB additions per year (kg m^{-2} yr^{-1}) for a) supratidal forests, b) saltmarsh and c) other land covers using the detailed approach.

Table 3.6: Productivity measures represented as mean values per year using the detailed approach.

Productivity measure	Land cover	Mean value
Vertical growth per year	Supratidal forest	0.508m/year
AGB gain per year (CCI Biomass)	Supratidal forest	0.489 kg/m^2/year
	Saltmarsh	0.6931 kg/m^2/year
	Other	1.145 kg/m^2/year

Interpretation and discussion

There are numerous indicators that could be used to determine condition at the detailed scale of analysis, however capacity to apply the best available indicators that aligned with the targets for restoration was limited by access to relevant data at both a spatial and temporal resolution suitable for assessing change in condition. Change in biomass or height is often used to indicate productivity, but this metric does not work well for low vegetation cover, such as saltmarsh, and is best suited to vegetation classes that increase height over time. In the case of the Hunter River, this indicator was largely suitable for supratidal forests as mangroves were not within the designated study area. In addition, when used to estimate biomass for saltmarsh, it provided an overestimate as the conversion to saltmarsh was regarded to be relatively recent and hence the total biomass had accumulated over only a few years, resulting in an estimate for productivity of saltmarsh in some cases being unexpectedly higher than for supratidal forests. Furthermore, the data used to indicate biomass, CCI biomass, was not available for the relevant opening and closing years, with the 2018 CCI biomass data being applied to quantify change in biomass in 2021. This limitation was substantial and emphasises the need to collect suitable data for assessing condition prior to the commencement of restoration activities.

Reflection relative to the Guide

The overall capacity to assess condition at the national scale and detailed level was dependent upon access to the best data available and that condition could be assessed using consistent methods. There are a range of other indicators that could be used to assess the structure, function and composition of an ecosystem, providing sufficient data was available (as expanded upon in the Guide). This could be resolved in future assessments when data availability improves, particularly when collection of pre-restoration data, specifically targeted for assessing condition relative to the restoration activity is prioritised prior to commencement of restoration.

It is also worthwhile emphasising that a condition indicator can be used to establish differences in condition between ecosystems, or over time, however a step change in condition between indicators is not an appropriate comparison, and should not be undertaken. For example, NDVI changes can be compared between ecosystems, or over time, but should not be compared to indicators of landscape greenness. To overcome this, condition was assessed within the same areas. For example, the condition of pre-restoration saltmarsh was compared to the condition of post-restoration saltmarsh, and these condition metrics were then used to assess the condition of areas that had changed from another ecosystem type to saltmarsh. This meant that condition was assessed in mutually inclusive areas at the opening and closing data as a priority, and these condition changes were used to ascertain whether the areas that had changed extent had also improved in condition. The secondary approach that quantified the extent that either declined or improved condition provided the best means of comparing condition within the same areas, and it is strongly advocated that this approach be undertaken in future assessments.

4. Measuring and accounting for ecosystem services

4.1 Physical ecosystem services and monetary accounts

This section provides the detailed analysis of the change in physical ecosystem services and monetary valuation estimates associated with the restoration project.

For an explanation of terms used throughout compared to SEEA please refer to Glossary of relevant Ecosystem Services from SEEA (**Section 7**).

4.2 Cultural services: recreational services

Intent of work

This section reports the physical and monetary accounts and also other values associated with the primary cultural services provided by the Tomago wetland restoration site. These include recreational related services. According to SEEA-EA, recreation-related services are defined as "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"[15]. In this case study, the focus is on two recreational services i.e. recreational fishing and bird watching; but we also considered values associated with the 'existence' of the restored habitat that may be held by those who do not visit it.

Note that accounts for the SEEA-EA are focused on services where an exchange has taken place; that is, either direct or indirect use of the restoration site or its exported services. For recreational fishing and bird watching this is possible. For these services, we are able to estimate 'exchange values' which reflect the prices paid for exchanges associated with the service, as summarised in the approach below.

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[15] United Nations. "*System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA). White cover publication, pre-edited text subject to official editing*" (2021). https://seea.un.org/ecosystem-accounting. p133.

Welfare values, which are also quantified in monetary terms, measure the total economic benefit that a service provides, rather than the price of exchanged items only. Estimation of welfare values can be particularly important for cultural ecosystem services, which include existence values and other forms of value that do not depend on use and exchanges occurring – these are referred to commonly as 'non-use' values in economic valuation. Accordingly, we also report on the welfare value associated with recreational fishing, bird watching, and the broader non-market values associated with the restored habitat at Tomago.

Approach taken

The physical recreational service accounts require data on: (i) the visitation rate by recreational users of the site (or adjacent areas, in the case of exported services); and (ii) the proportion of visits that can be attributed to the services provided by the restored habitat, relative to the number of visits that would occur had it not been restored. Following the recommendations in the Guide[16] exchange values are then calculated using trip expenditure data, where the price of associated trip expenses (e.g. fuel costs for vehicles) is applied per visit to the site.

There was no primary data available that recorded recreational activity at the site. Instead, to estimate Tomago's contribution to recreational fishing activities, we took the following steps:

- Data were obtained from NSW DPI that recorded number of fish caught and estimated annual fishing effort as number of fishing days for the whole of the Hunter River Estuary (HRE)[17,18].
- The stable isotope approach described in **Section 4.3.2** as used to estimate the contribution to biomass of recreationally caught species in the HRE from the mangrove and saltmarsh habitats within the restored wetland (noting that no/ negligible fishing activity occurs within the site due to accessibility).
- The proportion of fish catch attributable to the Tomago site could then be estimated considering the proportional size of mangroves and saltmarsh in the restored wetland (as provided in the Extent account) to the size of same ecosystems in HRE.
- The fishing effort (number of fishing days) is approximated using simple effort-to-catch ratio based on the catch and effort data available for the whole HRE.
- We converted fishing effort from the number of fishing days to the number of fishing trips, using data from a 2012 NSW survey (1.46 fishing days per trip)[19]. This step is needed as the exchange values must be reported on a per trip basis to establish the *physical account*.
- The same NSW survey provided estimates of travel expenditure per fishing trip, which was applied as the exchange value per fishing trip to establish the *monetary account*.
- A 2016 study reported consumer surplus estimates for recreational fishing day trips in Australia[20]. The dollar value from this study was applied to the number of fishing days attributable to the Tomago site to establish the *welfare value*.

[16] See the Guide for a summary of preferred methods to estimate exchange and welfare values.

[17] Dr. Matthew Taylor, Pers. Comm, *NSW Department of Primary Industries – Fisheries, Recreational Fisheries Research, Port Stephens Fisheries Institute, Department of Regional NSW*

[18] Taylor, M. D., et al. "The economic value of fisheries harvest supported by saltmarsh and mangrove productivity in two Australian estuaries." *Ecological Indicators* 84 (2018), 701-709. https://doi.org/10.1016/j.ecolind.2017.08.044

To estimate the contribution of Tomago to recreational birdwatching, we followed these steps:

- It is assumed that there was no birdwatching activity pre-restoration because of the site lost tidal connectivity healthy habitat for migratory and resident wetland birds.
- Anecdotal data on the number of people currently visiting the Tomago site for bird observing were provided through key informant interviews to establish the *physical account*.
- A 2022 study reported travel expenditure for day-trips to bird watching sites[21], which was applied as the exchange value per bird watching trip at Tomago to establish the *monetary account*.
- In 2019 another study estimated the consumer surplus per trip derived from birdwatching[22] (i.e. the value over and above expenditure) and this was applied to the estimate of number of trips to quantify *welfare values*.

To estimate the contribution to welfare values from Tomago's restored habitats, beyond the recreational services provided one requires an estimate of the existence value held by non-users for the restored area of wetland. There is a relative paucity of values in the literature that can be applied to a case study such as Tomago.

[19] McIlgorm, A., & J. Pepperell. "Developing a cost effective state wide expenditure survey method to measure the economic contribution of the recreational fishing sector in NSW in 2012." U*niversity of Wollongong, Wollongong*, NSW, Australia (2013).

[20] McLeod, P., & R. Lindner. "Economic dimension of recreational fishing in Western Australia." *Perth, WA: Recfishwest* (2018).

[21] Steven, R. "Bird and Nature Tourism in Australia." *BirdLife Australia* (2022).

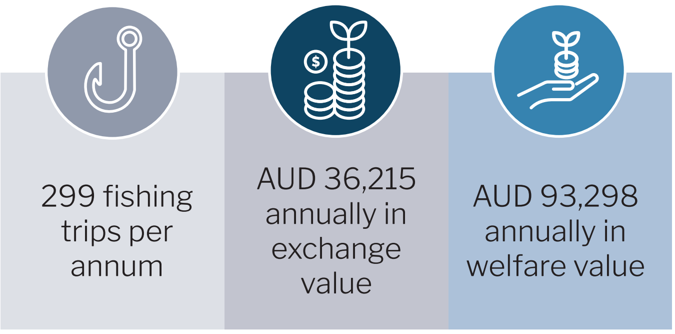
[22] Carnell, P., et al. "Mapping Ocean Wealth Australia: The value of coastal wetlands to people and nature." *The Nature Conservancy, Melbourne* (2019).

Results

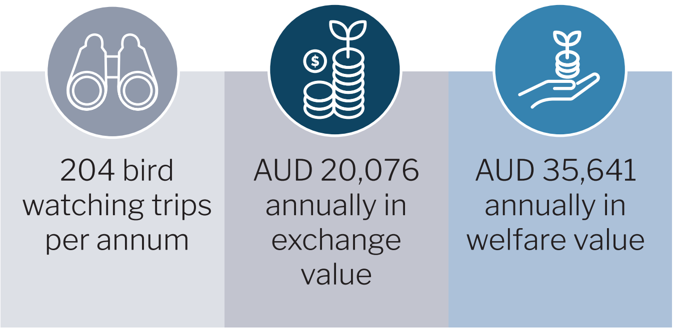
Note that the opening account assumes there is no supply of recreational services from the Tomago site given that pre-restoration the site was disconnected from the estuary and consisted of poor-quality habitat. We assume, therefore, that the export of fish biomass to adjacent areas was unlikely, and that the site was not frequented by many birds or bird species, such that no additional recreational services were being provided by the site beyond the services already being provided in adjacent areas.

Post-restoration results are provided below. These results should be interpreted as indicative-only, noting that estimates are based on anecdotal or extrapolated data rather than primary data and are unlikely to be accurate.

Recreational fishing services from the restoration activities are estimated to have contributed:



Recreational birdwatching services from the restoration activities are estimated to have contributed:



Additionally, other non-market values associated with existence of the restored habitats are estimated to have contributed $18,619 AUD annually in welfare value.

Reflection relevant to the Guide

The ability to implement the advice provided in the Guide has been challenging in this case study application primarily due to scarcity of relevant data. In this case study, resources did not permit for primary data collection and hence face the following specific challenges.

- Establishing the causal link between management action, ecological change, behavioural change has been challenging as not all parts of this causal chain have been researched and reported on for Tomago.
- Most visitation or other use-related data is provided at a larger spatial scale than that required for a restoration project, requiring assumptions and use of anecdotal evidence regarding the actual visitation attributable to the restoration site.
- Without site-specific visitation data there is also an absence of data about the socio-demographics of visitors, which reduces the ability to adjust secondary data used in benefit transfer, leading to reduced accuracy.
- For bird watching there were no locally relevant studies available to provide suitable monetary estimates for benefit transfer. Instead, national data had to be used for extrapolation leading to reduced accuracy.

If resources were available for other restoration projects, the ability to conduct primary research that would reliably enable estimation of monetary (exchange or welfare) values would be highly dependent on the available sample population using the site (i.e. there need to be sufficient sample available to estimate travel expenditures or consumer surplus measures with confidence).

Moving forward, it may be useful to improve data collection on visitation rates – before and after restoration – for project sites using structured sampling for objective data even for small/infrequently visited sites. Broadening of the associated non-market valuation literature could then focus on estimating exchange and welfare values for case study sites where there are large enough relevant human populations for a reliable analysis, and sites are targeted to build a representative database of non-market values for restored wetland ecosystem services to use in benefit transfer. Finally, as illustrated by the difference in magnitude of exchange and welfare values reported for recreational services, it is very important to consider what the objectives are for estimating and using monetary estimates of ecosystem services. The Guide provides advice on what values and economic tools are relevant for different types of common decisions.

Introduction to cultural services valuation

Wetlands in estuarine and coastal ecosystems are some of the most heavily used natural systems supporting several ecosystem services that provide important cultural and other benefits to humans[23,24,25]. Cultural ecosystem services[26] iinclude the various non-material benefits people obtain from nature (Millennium Ecosystem Assessment, 2005). Referring to the Common International Classification of Ecosystem Services (CICES)[27], examples of cultural services that wetlands may provide include services that imply use of the wetland such as nature-based recreation or aesthetic benefits, and services that may not require use of the wetland such as the benefits derived from the knowledge the wetland exists (existence value).

Use-related services are relevant for developing accounts, as these imply an exchange has taken place. At Tomago, recreation services are the most relevant direct use-value services for beneficiaries which needs to be properly accounted. They include common recreational activities like recreational fishing with significant social and economic values to human wellbeing and regional development[28].

Those services that may not rely on exchanges are relevant for other forms of economic valuation.

The Common International Classification of Ecosystem Services (CICES) describes nature-based recreation as, "using the environment for sport and recreation; using nature to help stay fit" and "watching plants and animals where they live; using nature to de-stress"[29]. Recreation-related services are defined in the SEEA EA as 'the ecosystem contributions, 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[30]. Examples of recreation-services of mangroves, salt marshes, and supratidal forests include activities such as recreational fishing, birdwatching, boating, and kayaking of local and non-local visitors[31,32].

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[23] Barbier, E. B., et al. "The value of estuarine and coastal ecosystem services." *Ecological Monographs*, 81(2) (2011), 169-193. https://doi.org/10.1890/10-1510.1.

[24] Huang, B., et al. "Quantifying welfare gains of coastal and estuarine ecosystem rehabilitation for recreational fisheries." *Science of The Total Environment*, 710 (2020), 134680. https://doi.org/10.1016/j.scitotenv.2019.134680.

[25] Gaylard, S., et al. "Review of Coast and Marine Ecosystems in Temperate Australia Demonstrates a Wealth of Ecosystem Services [Review]." *Frontiers in Marine Science*, 7 (2020). https://doi.org/10.3389/fmars.2020.00453.

[26] The term 'cultural services' is not implied that culture itself is a service, rather it is a collective label intended to capture the variety of ways in which people connect to, and identify with, nature and the motivations attributed to these connections (United Nations, 2021 p.130).

[27] Haines-Young, R., & M. B. Potschin. "Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure" (2018).

[28] McIlgorm, A., & J. Pepperell. "Developing a cost effective state wide expenditure survey method to measure the economic contribution of the recreational fishing sector in NSW in 2012." U*niversity of Wollongong, Wollongong*, NSW, Australia (2013).

[29] Haines-Young, R., & M. B Potschin. "Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure" (2018).

[30] United Nations. "System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA). White cover publication, pre-edited text subject to official editing. https://seea.un.org/ecosystem-accounting. p133."

[31] Barbier, E. B., et al. "The value of estuarine and coastal ecosystem services." *Ecological Monographs*, 81(2) (2011), 169-193. https://doi.org/10.1890/10-1510.

[32] Carnell, P. E., et al. "Mapping Ocean Wealth Australia: The value of coastal wetlands to people and nature." *The Nature Conservancy, Melbourne* (2019).

In this regard, Australia's coastal wetlands form recreational hotspots that offer opportunities for recreational fishing and nature-based tourism[33]. A national survey shows that about 4.2 million adult Australians were estimated to participate in recreational fishing each year with significant economic contribution[34]. In NSW waters alone, State-wide expenditure on recreational fishing was estimated at AUD 1.63 billion per year[35]. Recreational fishing is a popular interaction with coastal and marine environments where most of the recreational fishers' link participation to sport and relaxation with a significant benefit on health and well-being[36].

The Tomago wetland is primarily composed of saltmarsh and includes a few mangroves, supratidal forests, and others. The ecosystems are home to a range of species, particularly species of shorebirds and fish. The Tomago restoration project that started in the 1990's has contributed to improvements in ecosystem conditions including water quality and enhances wildlife habitat[37,38,39]. This could be considered as an enabling factor to experience selected recreational activities in and outside the wetland restoration site.

This report focuses on recreational fishing and birdwatching activities. There is limited evidence about other recreational activities attributed to the restoration site.

With respect to recreational fishing services, effective rehabilitation or restoration of wetlands can improve such services[40], for example, restoring basic saltmarsh structure through tidal connection was found to deliver substantial benefits for fish productivity in Tasmania[41]. Seagrass habitat in the gulf waters is associated with increased economic value of recreational fishing in South Australia[41]. Similarly, as the tidal connection is restored, Tomago's restoration might contribute to the improvement in ecosystems and wildlife habitat, such as increase in abundance of recreational fish species in the Hunter River Estuary (HRE). The most common fish species caught (and/or released) at HRE include tailor, bream, whiting and flathead[43].

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[33] Carnell, P. E., et al. "Mapping Ocean Wealth Australia: The value of coastal wetlands to people and nature." *The Nature Conservancy, Melbourne* (2019).

[34] Moore, A., et al. "National Social and Economic Survey of Recreational Fishers 2018-2021, February." *CC BY 3.0. Fisheries Research and Development Corporation* (2023).

[35] McIlgorm, A., & J. Pepperell. "Developing a cost effective state wide expenditure survey method to measure the economic contribution of the recreational fishing sector in NSW in 2012." U*niversity of Wollongong, Wollongong*, NSW, Australia (2013).

[36] Young, M. A. L., et al. "Why do fishers fish? A cross-cultural examination of the motivations for fishing." *Marine Policy*, 66 (2016), 114-123. https://doi.org/10.1016/j.marpol.2016.01.018.

[37] Glamore, W., et al. "Eco-hydrology as a driver for tidal restoration: Observations from a Ramsar wetland in eastern Australia." *PLoS ONE*, 16(8) (2021), e0254701. https://doi.org/10.1371/journal.pone.0254701.

[38] Lindsey, A. "The birds of Tomago Wetland after reinstatement of tidal flushing." *The Whistler* (2021), 6-26.

[39] Lindsey, A., & N. McNaughton. "Birds of Tomago Wetlands, Hunter Wetlands National Park 2007-2012." *The Whistler* (2012), 1-10.

[40] Huang, B., et al. "Quantifying welfare gains of coastal and estuarine ecosystem rehabilitation for recreational fisheries." *Science of The Total Environment*, 710 (2020), 134680. https://doi.org/10.1016/j.scitotenv.2019.134680.

[41] Prahalad, V., et al. "Expanding fish productivity in Tasmanian saltmarsh wetlands through tidal reconnection and habitat repair." *Marine and Freshwater Research*, 70 (2019), 140-151. https://doi.org/10.1071/MF17154.

[42] McLeod, P., & R. Lindner. "Economic dimension of recreational fishing in Western Australia: Research report for the recreational fishing initiatives fund." *Department of Primary Industries and Regional Government and Recfish west* (2018).

[43] Murphy, J. J., et al. "Survey of recreational fishing in NSW, 2019/20 – Key Results" (2022).

With respect to birdwatching activities, one of the main contributions of the Tomago restoration project is re-establishment of habitats for waterbirds[44,45]. According to the Hunter Bird Observers Club (HBOC) the diversity and abundance of waterbirds has increased following the three successive stages of restoration activities[46]. For instance, the overall count of waterbird species (including the shorebirds) has increased from 33 to 61 between 2012 and 2020[47]. In 2011/12, about 5000 birds were counted per day in the restoration area. The high numbers persisted from 2011/12 to 2018/19, with 1000+ birds being recorded each season, including Sandpiper recorded at Hexham Swamp and Tomago Wetland[48].

Note that the opening account assumes there is no supply of recreational services from the Tomago site given that pre-restoration the site was disconnected from the estuary and consisted of poor-quality habitat. A recreation logic chain can be used to describe the logical flow of assets, services and benefits (**Figure 4.1**). According to the recreation logic chain[49], the ecosystem assets consist of vegetation, open space, and surface water. The services are biotic and abiotic characteristics of nature recreation activities; and the benefits include health, recuperation, and enjoyment that people could receive from experiencing recreation.

The extent of the ecosystem for this case study is restricted to the Tomago Wetland restoration site boundary (given in the extent section of this report). However, this case study considers the provision of recreational services outside the restoration project boundary, acknowledging the contribution that the different ecosystem types (mangrove, saltmarsh, and supratidal forest) within the boundary make to recreational fishing and birdwatching activities occurring outside the project boundary. These are referred to as 'export' services.

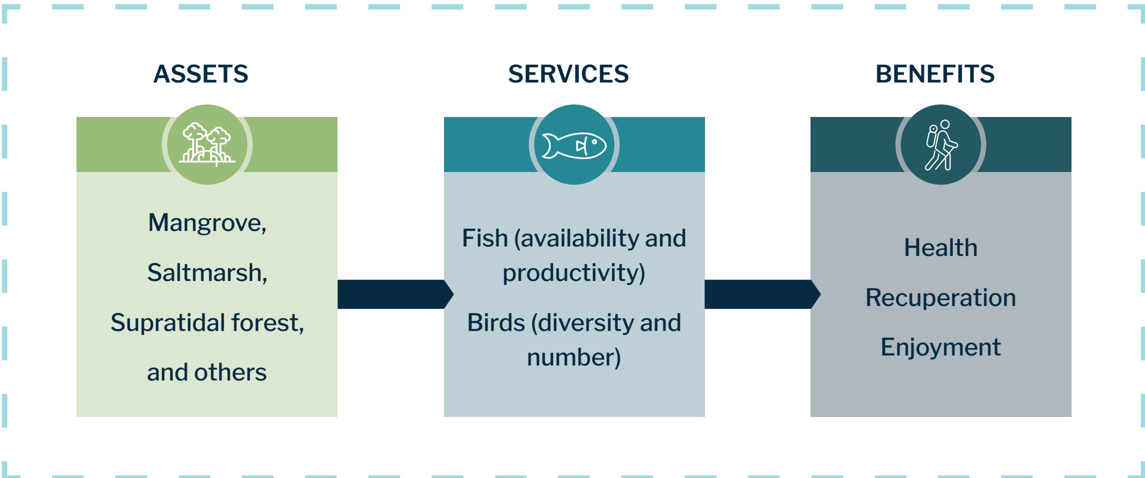

Figure 4.1: **A 'logic chain' for recreational services and benefits of Tomago wetlands** (Adopted from Barton et al., 2019[49]).

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[44] Lindsey, A. "The birds of Tomago Wetland after reinstatement of tidal flushing." *The Whistler* (2021), 6-26.

[45] Lindsey, A., & N. McNaughton. "Birds of Tomago Wetlands, Hunter Wetlands National Park 2007-2012." *The Whistler* (2012), 1-10.

[46] Stuart, A. "Hunter Region Annual Bird Report Number 25 (2017)." *N. L. Hunter Bird Observers Club Inc., Australia* (2018).

[47] Lindsey, A. "The birds of Tomago Wetland after reinstatement of tidal flushing." *The Whistler* (2021), 6-26.

[48] Stuart, A. "Recent high counts of Sharp-tailed Sandpiper in the Hunter River Estuary." *The Whistler*, 13 (2019), 6-61.

[49] Barton D. N., et al. "Discussion paper 10: Recreation services from ecosystems." *Paper submitted to the Expert Meeting on Advancing the Measurement of Ecosystem Services for Ecosystem Accounting, New York*, (2019).

Data availability

- State-wide Survey of Recreational Fishing in NSW 2019/20[50].
- Key informant consultation with Researchers at Department of Primary Industries, NSW) and at Water Research Laboratory, UNSW, UNSW Sydney.
- State-wide expenditure survey of recreational fishing in NSW waters[51].
- Proportionate contribution of Hunter River Estuary habitats (Mangrove and saltmarsh) to fish biomass productivity from '*stable isotopes*' studies[52].
- *Mapping the habitats of NSW estuaries*[53]. An estimate of the proportional area of mangrove and saltmarsh at Hunter River Estuary.
- Systematic literature review of recreation valuation studies (both peer review papers and research reports).

Methodology 1: Recreational services data

The objective of obtaining the physical measures of recreational services is to quantify the contribution of the restoration site for outdoor recreational services.

Physical accounts for recreational services can be established using different metrics, such as potential visitation, predicted visitation, actual visitation, and other measures based on subjective indicators (e.g. density of social media posts)[54]. Actual visitation is a metric based on counts of actual visits to the recreation sites and is the preferred measurement to establish use-accounts tables of recreational services according to the System of Environmental Economic Accounting Ecosystem Accounting (SEEA-EA) framework. This report relies on estimated total visitation rates to generate the use tables in the absence of primary data on actual visitation of the restoration site.

Recreational fishing data

There are no data available that provide direct estimates of the actual visitation to the Tomago restoration site. The state-wide reports of recreational fishing[55,56,57] are often on a larger spatial scale and difficult to disaggregate to a smaller scale like the Tomago restoration site. This case study relies on computed visitation rate based on recreational fish catch, and efforts data for selected fish species during the 12 months period of 2019/20) for the Hunter River Estuary (HRE), within which the Tomago wetland lies. The catch and effort data, (which is the most recent data), is obtained from Dr Matthew Taylor, Department of Primary Industries, NSW[58] and used to approximate the recreational fishing contribution of Tomago site as an export service[59].

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[50] Murphy, J. J., et al. "Survey of recreational fishing in NSW, 2019/20 – Key Results" (2022).

[51] McIlgorm, A., & J. Pepperell. "Developing a cost effective state wide expenditure survey method to measure the economic contribution of the recreational fishing sector in NSW in 2012." U*niversity of Wollongong, Wollongong*, NSW, Australia (2013).

[52] Taylor, M. D., et al. "The economic value of fisheries harvest supported by saltmarsh and mangrove productivity in two Australian estuaries." *Ecological Indicators*, 84 (2018), 701-709. https://doi.org/10.1016/j.ecolind.2017.08.044.

[53] Creese, B., et al. "Mapping the habitats of NSW estuaries: Report to the Hunter Central Rivers Catchment Management Authority." *Industry & Investment NSW* (2009).

[54] Barton D. N., et al. "Discussion paper 10: Recreation services from ecosystems." *Paper submitted to the Expert Meeting on Advancing the Measurement of Ecosystem Services for Ecosystem Accounting, New York*, (2019).

[55] Murphy, J. J., et al. "Survey of recreational fishing in NSW, 2017/18." *Fisheries Final Report Series*, 158 (2020).

[56] Murphy, J. J., et al. "Survey of recreational fishing in NSW, 2019/20 – Key Results" (2022).

[57] West, L. D., et al. "Survey of Recreational Fishing in New South Wales and the ACT, 2013/14." *Fisheries Final Report Series*, 149 (2015).

[58] Raoult, V., et al. "Habitat–fishery linkages in two major south-eastern Australian estuaries show that the C4 saltmarsh plant *Sporobolus virginicus* is a significant contributor to fisheries productivity." *Hydrobiologia*, 811(1) (2018), 221-238. https://doi.org/10.1007/s10750-017-3490-y.

[59] Taylor, M. D., et al. "The economic value of fisheries harvest supported by saltmarsh and mangrove productivity in two Australian estuaries." E*cological Indicators*, 84 (2018), 701-709. https://doi.org/10.1016/j.ecolind.2017.08.044.

The proportion of estimated total visitation rate attributed to the Tomago restoration site is approximated using a conversion factor that links the exported recreational fishing services of the site to adjacent fishing grounds. This approach quantifies the proportionate contribution of each habitat to the fish biomass productivity using 'stable isotopes' techniques as indicated in ecological studies[60,61,62]. The mangroves and saltmarshes of Tomago site are significantly contributing to the selected and recreationally important fish species at HRE[63]. The estimates on the contribution of mangroves and saltmarshes to recreational fish biomass at HRE is provided in the study by Taylor et al. (2018)[64] (**Table 4.1**). This case study considers the contribution of Tomago wetland ecosystems for the six most important fish species caught for recreation at the HRE (**Table 4.1**).

In this report, we used the amount of catch at HRE to be directly associated with effort (data sources summarized in **Table 4.2**).

The estimated contribution of Tomago site as fish habitat for recreational fishing outside the site is approximated using the following formula:

$$E_T = \gamma\alpha \sum(\beta_s P_s C_{sHRE})$$

HRE is the Hunter River Estuary, E_T= Effort at the Tomago site, γ is the effort-to-catch coefficient at estuary level, α is the proportional size of an ecosystem type at Tomago to the size of that ecosystem type at HRE, C_s is recreational fishing catch of a given species at HRE, β_s is coefficient of ecosystem contribution to fish productivity of each fish species based on 'stable isotopes', and P_s is coefficient of spatial partitioning attributed for each fish species. Spatial partitioning coefficient (P_s) was used to partition out the variability in species distribution along the estuary and its effect on catch and is intended to reflect the average spatial distribution of harvest along a greater length of estuary than that encompassed by the stable isotope data used to model the source contributions[65].

Table 4.1: Proportionate contribution of mangrove and saltmarsh to recreational fish biomass at HRE. Data sources: consultation with Dr. Matthew Taylor, Taylor et al. 2018[60]

Species	Catch at HRE (number)	Fishing effort at HRE (Fishing days)	Mangrove contribution	Saltmarsh contribution	Spatial partitioning (Ps)
Yellowfin Bream	15645		0.292	0.316	0.80
Mulloway	462		0.175	0.465	0.85
Dusky Flathead	9069		0.166	0.627	0.80
Ray (unspecified)	1669		-	-	-
Tailor	1295		-	-	-
Long Finned Pike	742		-	-	-
Total	28883	4841			

[60] Jänes, H., et al. "Stable isotopes infer the value of Australia's coastal vegetated ecosystems from fisheries." *Fish and Fisheries*, 21(1) (2020), 80-90. https://doi.org/10.1111/faf.12416.

[61] Raoult, V., et al. "Habitat–fishery linkages in two major south-eastern Australian estuaries show that the C4 saltmarsh plant *Sporobolus virginicus* is a significant contributor to fisheries productivity." *Hydrobiologia*, 811(1) (2018), 221-238. https://doi.org/10.1007/s10750-017-3490-y.

[62-65] Taylor, M. D., et al. "The economic value of fisheries harvest supported by saltmarsh and mangrove productivity in two Australian estuaries." *Ecological Indicators*, 84 (2018), 701-709. https://doi.org/10.1016/j.ecolind.2017.08.044.

So, estimation is performed in the following procedure:

- The contribution of each ecosystem (mangroves and saltmarsh) is calculated by multiplying the catch at HRE by the contribution coefficients and coefficient of spatial partitioning for each fish species. Note that contribution and spatial partitioning coefficients for three of the six species were not estimated and hence extrapolated by taking the average coefficients for all species provided in the study.

- The (proportional) catch provided by Tomago is evaluated by multiplying the total catch contribution of each ecosystem and the proportional size (i.e. area of Tomago ecosystem divided by total area of the ecosystem for HRE). Based on the extent account data, in 2022 mangrove and saltmarsh habitats in Tomago wetland were 2.8 hectare (ha) and 95.8 ha respectively. Based on earlier data the HRE has about 1922 ha of mangrove and 520 ha saltmarsh[66].

- The total proportional catch is then converted to Effort (fishing days) considering the effort-to-catch ratio. The effort-to-catch ratio is calculated using annual total catch of 28,883 and total effort (fishing days) of 4,841 in the HRE i.e. 6 fish caught per fishing day on average.

The metrics used to measure recreational fishing activities are the number of fishing trips. However, previous catch and effort surveys have documented data based on days fished. We used the data on the number of trips obtained from recreational fishing expenditure survey for NSW saltwaters (a fishing trip was estimated to be equal to 1.46 fishing days)[67] to compute the relationship between fishing days and trips for recreational fishing license holders in New South Wales (NSW) state.

Table 4.2: Summary of the data sources used for calculating recreational fishing data for Tomago.

Data type	Description	Source / Author	Note on how used
Fish catch	Number of fish caught (and/or released) at HRE	Matthew Taylor, Principal Research Scientist & Program Leader – Recreational Fisheries Research, Department of Primary Industries, Department of Regional NSW)	Catch-to-effort ratio used to translate the effort at Tomago
Fishing effort	Recreational fishing effort at HRE (fishing days)	Matthew Taylor, Principal Research Scientist & Program Leader – Recreational Fisheries Research, Department of Primary Industries, Department of Regional NSW)	
Contribution to fish biomass	Mangrove and Saltmarsh contribution to fish biomass productivity	Taylor et al., 2018[68]	Contribution coefficient of each ecosystem type and fish species used to translate catch at Tomago
Ecosystem at Hunter River Estuary (area)	Size of mangrove, saltmarsh, and other ecosystems of the Hunter River Estuary	Creese et al., 2009[66]	The contribution Tomago to fish biomass productivity based on the proportional area of mangrove and saltmarsh

[66] Creese, B., et al. "Mapping the habitats of NSW estuaries: Report to the Hunter Central Rivers Catchment Management Authority." *Industry & Investment NSW* (2009).

[67] McIlgorm, A., & J. Pepperell. "Developing a cost effective state wide expenditure survey method to measure the economic contribution of the recreational fishing sector in NSW in 2012." *University of Wollongong, Wollongong*, NSW, Australia (2013).

[68] Taylor, M. D., et al. "The economic value of fisheries harvest supported by saltmarsh and mangrove productivity in two Australian estuaries." *Ecological Indicators*, 84 (2018), 701-709. https://doi.org/10.1016/j.ecolind.2017.08.044.

Birdwatching data

Tomago wetland has a significant contribution for birdwatching as a recreational service. However, there is no well-documented information about the number of bird observers at the site before or after restoration. Instead, the data for bird observers is obtained anecdotally from key informants who know the area very well. In the process of data collection, several key informants including stakeholders at Water Research Laboratory of University of New South Wales, Hunter Wetland Centre, and Hunter Bird Observers Club were contacted. Virtual meetings were held with our key informants for asking questions about visitation data for recreational services, including for the birdwatching activities at the site (see **Appendix A1**. Data enquiry from Key Informants (Recreational fishing) for the list of questions).

The account for birdwatching is established using anecdotal evidence from expert consultation and contact with key informants (KI) for the restoration project at the site (Dr William Glamore and Alice Harrison at Water Research Laboratory, UNSW, UNSW Sydney, *pers comm*). According to the KIs, the restoration activities have contributed to increased bird watching opportunities inside and outside the restoration site and the number of bird observers has increased over time since restoration. Anecdotal data suggested that the number of bird observers at Tomago wetlands can be estimated within the range of 15-20 people per month. These bird observers were predominantly domestic, including local and nearby residents. Considering the seasonal differences of data on the number of birdwatchers, the annual visitation rate is calculated for both the lower and upper bound estimates. However, for this accounting purpose, a conservative estimate of median value (17 visitors per month) is used to estimate the annual visitation rate at Tomago site.

Methodology 2: Analysis approach for economic evaluation

According to the SEEA EA framework, the benefits and monetary value of ecosystem services can be estimated using exchange values. Since values for recreational services of natural ecosystems including coastal wetlands are not generally observed in the market, their monetary values are often estimated using non-market valuation (NMV) methods[69,70]. The two broad categories of NMV techniques are revealed preference (RP) and stated preference (SP) and these valuation techniques are based on primary data collection from a targeted study site. For example, recreation-related services are commonly estimated using data from travel cost methods and other stated preference methods such as choice experiments. These methods measure welfare values (**Table 4.10**) and hence such estimates do not provide market prices to be directly used as exchange values. An alternative approach is to use simulated exchange values – if a site-specific demand curve can be derived[71]. This also requires existing data on actual number of trips. In cases when primary data collection is not feasible due to time or other resource constraints the alternative option is to use a "Benefit Transfer" methodology[72], which is adopted here. This method employs techniques of transferring existing value estimates from closely related study or studies conducted in another location with a similar context in Australia or elsewhere. Most importantly in selection of relevant studies one has to consider that the valuation techniques are used to at least approximate exchange values for recreational services of a given site.

SEEA-EA provides a list of valuation methods and the preferred order of suggested methods to estimate the non-market values of ecosystem services including recreational services[73]. Among

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[69] Rolfe, J., & B. Dyack. "Valuing Recreation in the Coorong, Australia, with Travel Cost and Contingent Behaviour Models." *Economic Record*, 87(277) (2011), 282-293. https://doi.org.10.1111/j.1475-4932.2010.00683.x.

[70] Huang, B., et al. "Quantifying Welfare Gains of Coastal and Estuarine Ecosystem Rehabilitation for Recreational Fisheries." *Science of The Total Environment*, 710 (2020), 134680. https://doi.org.10.1016/j.scitotenv.2019.134680.

[71] Caparrós, A., et al. "Simulated Exchange Values and Ecosystem Accounting: Theory and Application to Free Access Recreation." *Environmental economics*, 139 (2017), 140-149. https:/doi.org.10.1016/j.ecolecon.2017.04.011.

[72] Johnston, R. J., et al. (Eds.). Benefit Transfer of Environmental and Resource Values: A Guide for Researchers and Practitioners. *Dordrecht, Netherlands: Springer* (2015).

[73] United Nations. System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA). White cover publication, pre-edited text subject to official editing (2021). https://seea.un.org/ecosystem-accounting. p. 133.

them is travel expenditure. Travel expenditure includes costs of travelling in the form of transport costs and /or accommodation costs incurred by households or individuals to visit recreational sites. Consistent with SEEA-EA, these costs are based on actual expenditures of marketed goods and services to reach recreation sites and hence can provide an exchange value for recreational services that ecosystems provide to visitors[74].

In this report, the monetary values of recreational fishing and birdwatching are estimated based on exchange value estimates using a benefit transfer methodology, i.e. applying measures of similar studies on valuation of coastal and estuarine ecosystems and specifically wetlands in other locations in Australia. The literature reviews for this purpose followed an extensive systematic search of recreational value estimates from 'Web of Science' and 'Scopus' databases (with some additional literature from Google Scholar) including studies in the peer-reviewed scientific literature, working papers and research reports; of these research reports constitute about 42% of the primary valuation studies of our dataset. Additionally, the search extended to checking reference lists in reviewed articles for additional studies and related reports that had focused on estuary wetland valuation studies in Australia. The search strategy is summarized as follows:

- The searching framework used the following combinations of key words:
  - (("Travel cost" OR contingent OR "choice experiment" OR "discrete choice" OR economic OR valu* OR monetary OR "willingness to pay" OR WTP) AND (mangrove* OR seagrass* OR saltmarsh* OR "salt marsh" OR marine* OR river* OR estuar* OR coastal* OR wetland*) AND (recreat* OR ecotourism) AND (fish* OR angler* OR "Bird watching" OR birdwatching) AND (Australia)).
- As there were only limited number of valuations about birdwatching, the searching framework for valuation data was slightly modified by using a combination of additional key terms related to birdwatching as follows:
  - (("Travel cost" OR contingent OR "choice experiment" OR "discrete choice" OR economic OR valu* OR monetary OR "willingness to pay" OR WTP) AND (mangrove* OR wetland*) AND (Bird* OR Birding OR "Bird watching" OR birdwatching OR Avitourism OR twitching) AND (Australia)).
- Each paper was screened based on the abstract; then thoroughly reviewed for its relevance based on what it valued (e.g. recreational services), ecosystem type (estuarine or wetlands), valuation approach. Valuation studies included those that used travel and or consumer expenditure, travel cost methods, contingent valuation, and choice experiments with estimated economic values for recreational fishing and birdwatching at estuarine wetlands.
- The final list of valuation studies identified for valuation database included 13 for recreational fishing (eight peer reviewed papers and five research reports, the latter comprise 38.5 %) and four (two peer reviewed and two research reports) for birdwatching across Australia.

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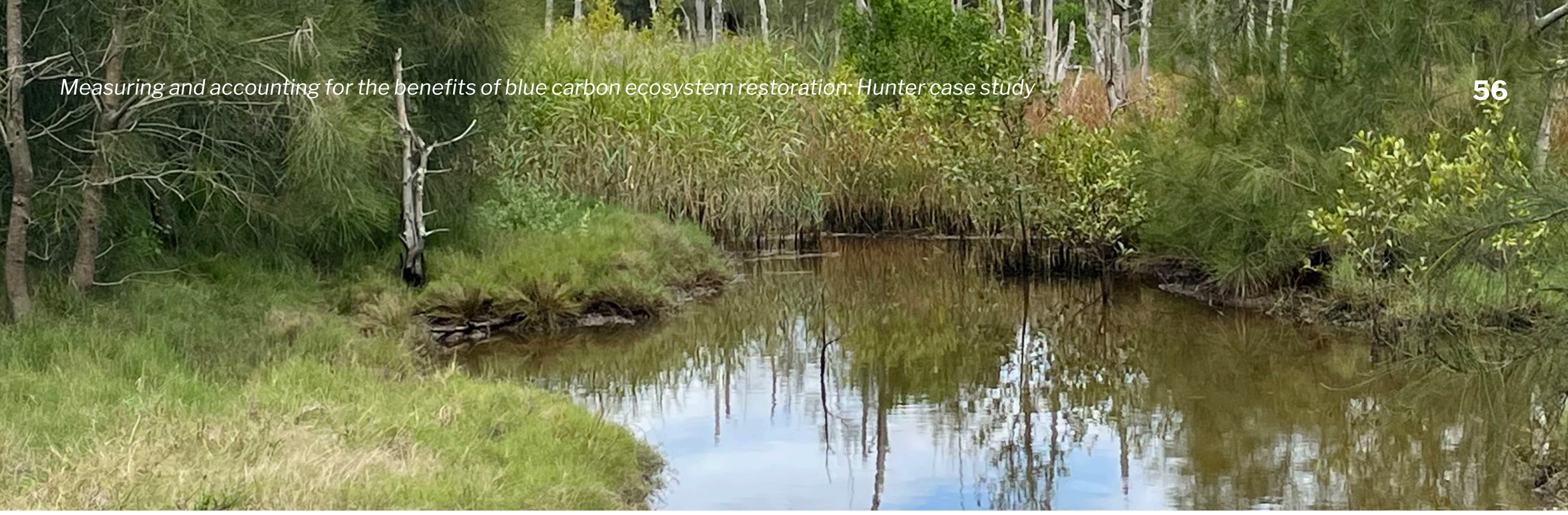
[74] NCAVES & MAIA. "Monetary valuation of ecosystem services and ecosystem assets for ecosystem accounting: Interim Version", *United Nations Department of Economic and Social Affairs, New York* (2022).



Values for recreational fishing

The valuation data on estimates of expenditure values was compiled from Australian studies (see also **Appendix A2**). Additional information such as valuation methods used, value measurement (per person per trip or per day), year of study, habitat type and other context-based information of study site characteristics such as visitor type and origin were also gathered to help assess whether the study population were comparable on certain socioeconomic and demographic characteristics to undertake adjustments. Overall, the compiled valuation data included six studies with expenditure data for recreational fishing in coastal saltwaters (**Table 4.3**).

A survey of expenditure on recreational fishing in NSW conducted in 2012 by McIlgorm and Pepperell (2013)[75] provided travel expenditure estimates for recreational fishing in NSW salt waters. This study was identified as suitable for value benefit transfer to the Tomago site because the methodology is consistent with the SEEA-EA recommendation that travel expenditure for recreational services can be used to approximate for exchange values. Furthermore, the study is applied in NSW where Tomago wetland is situated in the lower HRE region. Based on the selected study the estimated value of recreational fishing was, on average, AUD 96 per angler per trip in 2012, which is used for value benefit transfer for the Tomago case after adjusting by Australian consumer price index (CPI)[76].

Values for birdwatching

There were only four birdwatching valuations studies in Australia with two based on expenditure survey methods and the remaining two used the travel cost or choice modelling approach (**Appendix B** - **Table B.1**). Only two studies that are found relevant for exchange values based on travel expenditure are given in **Table 4.4**.

Steven (2022)[77] estimated the economic value of birdwatching using data of domestic birdwatchers', who listed birdwatching as an activity in their list of potential nature and outdoor activities for a daytrip made in Australia in 2019 using travel expenditure method. This valuation estimate included the expenditure (with no accommodation) incurred for travelling to the site, which is in line with the SEEA-EA approach on monetary valuation for recreational services[78]. The study used actual visitation data of the domestic population, with trips dominated by those travelling for less than 100 kms to the recreational site[79]. The estimate from this study given in **Table 4.5** is used for value transfer to estimate the economic value of birdwatching at the Tomago wetland site. Birdwatching information about the Tomago site showed that bird observers visiting the site and adjacent wetlands such as at Hexham site are mainly locals or nearby residents.

[75] McIlgorm, A., & J. Pepperell. "Developing a cost effective state wide expenditure survey method to measure the economic contribution of the recreational fishing sector in NSW in 2012." *University of Wollongong, Wollongong*, NSW, Australia (2013).

[76] Reserve Bank of Australia. "Measures of Consumer Price Inflation". *Inflation calculator*. https://www.rba.gov.au/calculator/ (accessed 31 March 2023).

[77] Steven, R. "Bird and Nature Tourism in Australia." *BirdLife Australia*. (2022).

[78] NCAVES & MAIA. "Monetary valuation of ecosystem services and ecosystem assets for ecosystem accounting: Interim Version", *United Nations Department of Economic and Social Affairs, New York* (2022).

[79] Steven, R. "Bird and Nature Tourism in Australia." *BirdLife Australia*. (2022).

Table 4.3: List of selected expenditure based recreational valuation studies in Australia.

Study	Year valued	Habitat	State/ Region/ location	Valuation method	Value measurement	Estimated value (AUD)
Farr and Stoeckl, 2018[80]	2012	Great Barrier Reef coast catchment	Townsville, Queensland	Expenditure	per angler/trip	66
Kandulu et al., 2021[81]	2019	Queensland Saltwaters	Cairns, Queensland	Expenditure (trip costs)	per angler/ trip	84
McLeod and Lindner, 2018[82]	2018	Saltwaters	Western Australia	Expenditure (Boat fuel, parking, bait & trip related costs)	per angler/trip	123
McLeod and Lindner, 2018	2018	Saltwaters	Western Australia	Expenditure (Weighted mean)	per angler/trip	147
McIlgorm and Pepperell, 2013	2012	Saltwaters	NSW	Travel expenditure (car and related)	per angler/trip	96
McIlgorm and Pepperell, 2013	2012	Saltwaters	NSW	Trip expenditure (including travel, fishing tackle and other equipment)	per angler/trip	141
Pascoe et al., 2014[83]	2013	Multipurpose coastline	Moreton Bay, Queensland	Expenditure (Fuel cost only	per angler/trip	36
Pascoe et al., 2014	2013	Multipurpose coastline	Moreton Bay, Queensland	Expenditure (car travel cost)	per angler/day	92
Prayaga et al., 2010[84]	2010	Coastal beaches	Capricorn Coast, Queensland	Expenditure	per angler/trip	196

Table 4.4: List of birdwatching expenditure-based valuation studies in Australia.

Study	Year valued	Habitat	State/region	Valuation method	Value measurement	Estimated value (AUD)
Steven, 2022	2019	Key Biodiversity Areas (KBAs)	National (Australia)	Travel expenditure	per day (with no accommodation)	89
Steven, 2022	2019	Key Biodiversity Areas (KBAs)	National (Australia)	Travel expenditure	per person per trip expenditure with overnight stay (inc. accommodation)	717
Callaghan et al., 2020[85]	2020	Old Bar, New South Wales	NSW, Australia	Expenditure (including travel time)	per person per trip	624
Callaghan et al., 2020	2020	Old Bar, New South Wales	NSW, Australia	Expenditure (excluding travel time)	per person per trip	532

[80] Farr, M., & N., Stoeckl. "Overoptimism and the undervaluation of ecosystem services: A case-study of recreational fishing in Townsville, adjacent to the Great Barrier Reef." *Ecosystem Services*, 31 (2018). 433-444. https://doi.org/10.1016/j.ecoser.2018.02.010.

[81] Kandulu, J., et al. "Economic contribution of recreational fishing by Queenslanders to Queensland: A Report for Fisheries Queensland." *Fisheries Queensland* (2021).

[82] McLeod, P., & R. Lindner. "Economic dimension of recreational fishing in Western Australia: Research report for the recreational fishing initiatives fund." *Department of Primary Industries and Regional Government and Recfish west* (2018).

[83] Pascoe, S., et al. "Economic value of recreational fishing in Moreton Bay and the potential impact of the marine park rezoning." *Tourism Management*, 41 (2014). 53-63. https://doi.org/10.1016/j.tourman.2013.08.015.

[84] Prayaga, P., et al. "The value of recreational fishing in the Great Barrier Reef, Australia: A pooled revealed preference and contingent behaviour model." *Marine Policy*, 34(2) (2010). 244-251. https://doi.org/10.1016/j.marpol.2009.07.002.

[85] Callaghan, C. T., et al. "Birds are valuable: the case of vagrants." *Journal of Ecotourism*, 19(1) (2020). 82-92. https://doi.org/10.1080/14724049.2019.1614010.

Table 4.5: List of expenditure-based valuation studies and values selected for benefit transfer.

Title	Ecosystem services Measured	Information taken from the study	Actual AUD 2022 value, CPI adjusted	Suitability to BT	Reference
Developing a cost-effective state-wide expenditure survey method to measure the economic contribution of the recreational fishing sector in NSW in 2012	Recreational fishing	Estimated value: AUD 96 per angler per trip (2012 AUD value)	Estimated value: AUD 121 per angler per trip	Tomago wetlands within the Hunter River Estuary is part of the study	McIlgorm and Pepperell, 2013[86]
Bird and Nature Tourism in Australia	Birdwatching	Estimated value: AUD 89 per trip, 2019 AUD value	Estimated value: AUD 98.41 per trip	'birdwatching' was listed as nature and outdoor activities in the survey	Steven, 2022[87]

Results

Recreation services (fishing and birdwatching) use accounts

Following the SEEA-EA framework, the physical account for the selected recreational services pre-restoration and post-restoration are presented in **Tables 4.6** and **4.7**. Recreational fishing is presented in fishing trips. The opening account (pre-restoration, 2007) assumes no supply of recreational services from the Tomago site given that during pre-restoration the site was disconnected from the estuary and consisted of poor-quality habitat. Post-restoration (2022) is associated increased recreational activities with improved habitat due to restoration. The recreational services data are based on anecdotal or extrapolated information. The total level of recreational fishing is estimated to be 299 fishing trips and 449 fishing days in 2022. For birdwatching, there were about 204 bird observers in 2022 based on the anecdotal evidence. The post restoration data is then considered as changes in recreational activities due to the restoration of Tomago site.

Monetary account for recreational fishing and birdwatching

The monetary accounts for the two recreation services are summarized below following the SEEA-EA account tables. **Table 4.8** presents the pre-restoration monetary account for the two recreational services. The post- restoration monetary account, which also represents the account for the changes after pre-restoration, for the recreational activities is also presented in **Table 4.9**. Monetary values are estimated by multiplying the physical flow of the service recorded in the physical accounts (**Tables 4.6** and **4.7**) by relevant values for each service (**Table 4.5**) that reflect their exchange values per unit. The estimated recreational values from the literature have been adjusted to 2022 Australian dollar values using the Australian consumer price index (CPI). Recreational fishing and birdwatching services from the restoration activities are estimated to have contributed AUD 36,215 and AUD 20,076 per annum, respectively.

[86] McIlgorm, A., & J. Pepperell. "Developing a cost effective state wide expenditure survey method to measure the economic contribution of the recreational fishing sector in NSW in 2012." *University of Wollongong, Wollongong*, NSW, Australia (2013).

[87] Steven, R. "Bird and Nature Tourism in Australia." *BirdLife Australia*. (2022).

Table 4.6: Physical account: annual supply and use of recreational services (pre-restoration, 2006).

	Units of measurement	Economic units				Ecosystems						
		Industry	Government consumption	Household consumption	Total use by economic units	Mangroves MFT1.2	Saltmarsh MFT1.3	Supratidal forests MFT1.2	Intertidal seagrass M1.1	Mudflats MT1.2	Other land covers T7.1	Total supply
Supply												
Recreational fishing (trips)	Number											0
Birdwatching (visitors)	Number											0
Use												
Recreational fishing (trips)	Number				0							
Birdwatching (visitors)	Number				0							

Table 4.7: Physical account: annual supply and use of recreational services (post-restoration, 2022 base).

	Units of measurement	Economic units				Ecosystems						
		Industry	Government consumption	Household consumption	Total use by economic units	Mangroves MFT1.2	Saltmarsh MFT1.3	Supratidal forests MFT1.2	Intertidal seagrass M1.1	Mudflats MT1.2	Other land covers T7.1	Total supply
Supply												
Recreational fishing (trips)	Number					1.3	298					***299.3***
Birdwatching (visitors)	Number											***204***
Use												
Recreational fishing (trips)	Number			299.3	***299.3***							
Birdwatching (visitors)	Number			204	***204***							

Table 4.8: Monetary account: annual supply and use of recreational services in monetary terms (pre-restoration, 2006; AUD, 2022 base).

	Units of measurement	Economic units				Ecosystems						
		Industry	Government consumption	Household consumption	Total use by economic units	Mangroves MFT1.2	Saltmarsh MFT1.3	Supratidal forests MFT1.2	Intertidal seagrass M1.1	Mudflats MT1.2	Other land covers T7.1	Total supply
Supply												
Recreational fishing (trips)	Number											0
Birdwatching (visitors)	Number											0
Use												
Recreational fishing (trips)	Number				0							
Birdwatching (visitors)	Number				0							

Table 4.9: Monetary account: annual supply and use of recreational services in monetary terms (post-restoration, 2022, AUD 2022 base).

	Units of measurement	Economic units				Ecosystems						
		Industry	Government consumption	Household consumption	Total use by economic units	Mangroves MFT1.2	Saltmarsh MFT1.3	Supratidal forests MFT1.2	Intertidal seagrass M1.1	Mudflats MT1.2	Other land covers T7.1	Total supply
Supply												
Recreational fishing (trips)	Number					157	36058					*36,215*
Birdwatching (visitors)	Number											*20,076*
Use												
Recreational fishing (trips)	Number			*36,215*	*36,215*							
Birdwatching (visitors)	Number			*20,076*	*20,076*							

Interpretation and discussion

The main recreational services attributed to and valued at the Tomago wetlands are recreational fishing and birdwatching. The two recreational services were negligible before the restoration because of the degradation of the wetland ecosystem and the lack of tidal connectivity to the wetland. The successive stages of restoration, however, restored the tidal connection and improved the habitat quality providing suitable ground for recreational fishing as well as significant habitat for migratory shorebirds, which includes species protected under Ramsar conventions.

Based on the contribution of Tomago ecosystems to fish biomass at the estuary level, as an export service, the recreational fishing effort attributable to the Tomago site is estimated at 299 fishing trips per annum. However, note that the change in physical accounts is entirely dependent on the extent account. A more accurate measure of the change could be calculated if actual visitation is directly measured at the restoration site over time. There were 204 trips for birdwatching per annum. These values can reflect the positive impacts of the restoration in enhancing wildlife habitat. Recreational services flow in monetary terms are estimated by multiplying the physical flow of the service by relevant exchange values for each service. For recreational fishing, the annual monetary estimated value is AUD 36,215 in 2022 value. Additionally, the annual value of recreational services from birdwatching totalled AUD 20,076 in 2022 value. These estimated values suggest that restoration programs such as that in Tomago wetlands can generate substantial societal benefits through different recreational activities.

While having accurate exchange value data is also important, the accuracy of values estimated through benefit transfer is likely to be improved through provision of more accurate visitation data. For example, for activities such as recreational fishing, there is usually data available at the regional or State-wide scale on fishing effort and trip expenditure, which can be applied with reasonable accuracy if visitation rate is known.

Welfare values of cultural services (using consumer surplus)

There are multiple frameworks that can be used to identify the value associated with the ecological services provided by an asset and hence the value of the asset. The exchange value approach outlined above is consistent with the national accounting framework but does not include values that may not pass through markets. As outlined in the Guide, an alternative approach is to estimate the welfare values associated with use and non-use.

In economic terms, well-being is commonly described in terms of welfare and utility, for which the economic values are measured using consumer surplus. Consumer surplus for recreational fishing services can be estimated with the use of non-market valuation methods such as revealed preference and stated preference techniques. The travel cost method (which is commonly used in the case of recreational activities, including fishing and bird watching) estimates the economic value based on people's behaviour to reveal their WTP for a good or service, while choice experiment, a stated preferences approach, is based on people's hypothetical preferences for the good or bundle of services that the ecosystem provides[88]. Where primary studies are not feasible, benefit transfer of values from similar studies can be employed.

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[88] Rolfe, J. & B. Dyack. "Valuing Recreation in the Coorong, Australia, with Travel Cost and Contingent Behaviour Models*." *Economic Record*, 87 (2011), 282-293. https://doi.org/10.1111/j.1475-4932.2010.00683.x

Welfare value of recreational fishing services

For this project, a benefit transfer of values from a similar non-market valuation study conducted elsewhere was carried out (listed in **Table 4.10**). A study by McLeod and Lindner[89] that estimated the economic values of recreational fishing was selected for two reasons. Firstly, it specifically focuses on boat-based marine fishing that suits the case in Tomago. Secondly, the study followed a meta-analysis approach of investigating over 15,000 consumer surplus estimates that were standardized to the Australian context. Overall, the consumer surplus estimate of this study was AUD 178 per angler per fishing day for the year 2016. Thus, the values can be transferred to our case study area, which aims at valuing the recreational benefits of Tomago wetlands. The final values were adjusted to 2022 value (AUD 207.79/angler/fishing day) using the Australian consumer price index (CPI).

Based on the contribution of Tomago ecosystems to fish biomass at the estuary level, the recreational fishing effort attributable to the Tomago site is estimated at 499 fishing days per annum. These values reflect the positive impacts of the restoration in enhancing wildlife habitat, and subsequently people's enjoyment in benefiting from the recreation opportunities that the enhanced habitat provides. Recreational services flow in monetary terms are estimated by multiplying the physical flow of the service by relevant welfare values for each service. Overall, the annual welfare value for recreational fishing based on the consumer surplus estimate is AUD 93,298 (**Table 4.11**).

Welfare value of birdwatching services

Due to lack of primary data to estimate the recreational benefit of saltmarsh and mangrove ecosystems of Tomago for birdwatching, we used a benefit transfer from a previous Australian study. Carnell et al. (2019)[90] estimated the economic value of birdwatching using welfare value estimates for travelling to view birds to the coastal ecosystem of Port Phillip, Victoria. This choice modelling study appears to be relevant and suitable to be used for value benefit transfer to our case study for two reasons (**Table 4.10**). Firstly, the data on bird observers is based on actual registration of the number of trips of birdwatchers visiting wetlands, specifically, the saltmarsh and mangrove ecosystems. Secondly, the valuation in the study aims estimating values of recreational benefit of birdwatching using the SEEA framework. The estimated consumer surplus value of coastal wetlands was, on average, AUD 158 per visit, which is used for value benefit transfer for the Tomago case.

Therefore, economic value birdwatching at Tomago site is estimated by multiplying standardised 2022 AUD value using Australian CPI value with the visitation rates obtained anecdotally. Overall, the estimated value for birdwatching based on the consumer surplus is AUD 35,641 (**Table 4.11**).

[89] McLeod, P., & R. Lindner. "Economic dimension of recreational fishing in Western Australia: Research report for the recreational fishing initiatives fund." *Department of Primary Industries and Regional Government and Recfish west* (2018).

[90] Carnell, P. E., et al. "Mapping Ocean Wealth Australia: The value of coastal wetlands to people and nature." *The Nature Conservancy, Melbourne* (2019).

Table 4.10: List of valuation studies with consumer surplus values used for value benefit transfer for welfare estimates.

Title	Ecosystem services Measured	Information taken from the study	Actual AUD 2022 value, CPI adjusted	Suitability to BT	Reference
Economic dimension of recreational fishing in Western Australia: Research report for the recreational fishing initiatives fund	Recreational fishing	Estimated values: AUD 178 per person per day, 2016 value	Estimated values: AUD 207.79 per person per day	Boat-based marine fishing; standardized multiple Australian studies with estimated values by angler per fishing day	McLeod and Lindner, 2018[91]
Mapping Ocean Wealth Australia: The value of coastal wetlands to people and nature.	Birdwatching	Estimated values: AUD158 per visit, 2019 value	AUD 174.71 per person per visit	Domestic visitors dominate local bird watching activities and valuation fol-lowed the SEEA framework	Carnell et al., 2019[92]

Table 4.11: Economic valuation using welfare values (consumer surplus): annual supply and use of recreational services of Tomago in monetary terms (AUD, 2022 base).

Ecosystem services	Measurement unit	Fishing days/ trips in 2022	Annual consumer surplus (AUD)
Recreational fishing	Number of fishing days	499	93,297.71
Birdwatching	No of trips	204	35,640.80

Welfare value of other non-use services

As noted in the Guide, welfare values are not limited to those that arise through use. Existence values reflect that people may value nature not because they use or intent to use it but for its mere existence[93]. As such, people may have an existence value for wetlands, and enjoy an increase in welfare as a result of the remediation of the site. This value will depend on both the change in extent of the wetlands, and also the improvement in the condition of the wetlands. This value will depend on both the change in extent of the wetlands, and also the improvement in the condition of the wetlands.

Although the change in condition/extent may be readily identified for the remediation site, linking these values to the metrics used in valuation studies is more problematic, where often the approach is to define an improvement in quality in ways that the public can easily interpret (i.e. fish populations, water quality). This goes to an issue raised by Xu et al. (2020)[94] on the need for unified wetland ecosystem services indicators.

[91] McLeod, P., & R. Lindner. "Economic dimension of recreational fishing in Western Australia: Research report for the recreational fishing initiatives fund." *Department of Primary Industries and Regional Government and Recfish west* (2018).

[92] Carnell, P. E., et al. "Mapping Ocean Wealth Australia: The value of coastal wetlands to people and nature." *The Nature Conservancy, Melbourne* (2019).

[93] Davidson, M. D. "On the relation between ecosystem services, intrinsic value, existence value, and economic valuation." *Ecological Economics*, 95 (2013), 171–177. https://doi.org/10.1016/j.ecolecon.2013.09.002.

[94] Xu, X., et al. "Wetland ecosystem services research: A critical review." *Global Ecology and Conservation* 22 (2020): e01027. https://doi.org/10.1016/j.gecco.2020.e01027.

Table 4.12: Estimates of existence values for Tomago wetland (total consumer surplus per year in 2022 base).

Study	Original WTP estimate (AUD per 1000ha/year/ household in 2010)	Adjusted WTP (AUD/1000ha/year/ household in 2022)	Present value WTP (AUD/1000ha/year/ household in 2022)	Total consumer surplus (AUD/ year)
MacDonald & Morrison (2010)[95]	1.36	2.18	0.63	18,619

In the absence of primary data or wetland valuation studies specific to Tomago wetland, we derive values based on a benefit transfer approach. We have conducted a systematic review of studies on non-use (existence) valuation of wetlands in Australia. After screening and reviewing abstracts, six studies were identified to be relevant. Among them, MacDonald & Morrison (2010)[95] provides estimates of WTP for an increase in the size and improvement of the quality of wetlands in South Australia based on surveys in Adelaide, Upper South East, and State-wide respondents. The study is best suited to our Tomago case study in terms of the valuation scope with WTP for wetland conservation. The WTP at State level is AUD 1.36 per 1000 hectare per household for a maximum of five years.

The original value of WTP is adjusted to the 2022 price level using CPI and by household income level for Newcastle residents in New South Wales, to AUD 2.18. Since the WTP in the original study is defined as the amount that respondents would pay per year for a 5-year period, this needs to be converted into a NPV value, and then an annuity value. We do this using a 7 % discount rate. The 5 years of payments is equivalent to an NPV of AUD 8.94, and the equivalent annuity of AUD 0.63 per year, per household, for a restored area of 1000ha. In determining an existence value, the appropriate population needs to be defined i.e. which community is benefited by the restoration. As a relatively small area, it is assumed that it is of relevance to the population of Newcastle only. The welfare value is estimated based on the consumer surplus corresponding to the size of restoration area multiplied by the total household population of Newcastle which is about 66,129[96]. Therefore, the existence value for the Tomago restoration site is estimated at about AUD 18,619 per year (in 2022 value, **Table 4.12**).

Reflection relevant to the Guide

The ability to implement the advice provided in the Guide has been challenging in this case study application primarily due to scarcity of relevant data. Specific challenges are documented below.

- Establishing the causal link between management action, ecological change, behavioural change has been challenging as not all parts of this causal chain have been researched and reported on for Tomago.
- Most visitation or other use-related data is provided at a larger spatial scale than that required for a restoration project, requiring assumptions to be made regarding the proportion of visitation attributable to the restoration site.
- Assumptions necessarily relied on the anecdotal evidence from researchers/ managers in the field, which does not allow for a more precise understanding of visitation including seasonal variations.
- Without site-specific visitation data, there is also an absence of data about the socio-demographics of visitors, which reduces the ability to make adjustments of secondary data used in benefit transfer (i.e. for income or other characteristics that may differ between the source and target sites), leading to reduced accuracy.

[95] MacDonald, H. D. & M. D Morrison. "Valuing biodiversity using habitat types." *Australasian Journal of Environmental Management*, 17 (2010), 235-243. https://doi.org/10.1080/14486563.2010.9725271

[96] Australian Bureau of Statistics (2021 census): https://www.abs.gov.au/census/find-census-data/search-by-area

- For bird watching there were no locally relevant studies (even at the regional level) available to provide suitable monetary estimates for benefit transfer. Instead, national data had to be used for extrapolation leading to reduced accuracy.

In this case study application, the resources did not permit primary data collection, hence the challenges above. However, if one assumed resources were available to allow this for other restoration projects, the ability to conduct primary research that would reliably enable estimation of monetary (exchange or welfare) values would be highly dependent on the available samples of people using the site (i.e. there would need to be sufficient sample available to statistically estimate travel expenditures or consumer surplus measures with confidence). A particular challenge here is that the recreational fishing benefits occur off site i.e. the environmental service of improved fish stock is 'exported' to areas around the site. Where to define the boundary of those benefits requires both an understanding of the ecology and larger scale fishers' behaviour.

Moving forwards, it may be useful to improve data collection on visitation rates – before and after restoration – for project sites. This requires structured sampling for objective data to be recorded but is technically feasible to implement even for small/infrequently visited sites. Where a restoration substantially improves the quality for the fishing experience, a more formal model of site choice would allow one to simulate the change in visitation rates to areas outside the restoration site.

Besides the two recreational services, other relevant economic indicators (such as the number of jobs created) could also be reported to better understand the economic contribution of recreational services. However, estimates of such indicators would require a robust estimate of supply, use, and exchange values than we have available in this case study. So, primary data collection would be ideal to integrate such indicators in reports.

Broadening of the associated non-market valuation literature could then focus on estimating exchange and welfare values for case study sites where the relevant human populations are large enough to allow for a reliable analysis to take place, and ensuring that sites are targeted to build a representative database of non-market values for restored wetland ecosystem services to use in benefit transfer (i.e. supporting extrapolation of monetary values to those sites were primary data collection is infeasible).

Finally, as illustrated by the difference in magnitude of exchange and welfare values reported for recreational fishing services, it is very important to consider what the objectives are for estimating and using monetary estimates of ecosystem services. The Guide provides advice on what values and economic tools are relevant for different types of common decisions with this in mind.

4.3 Provisioning services

Note work on SEEA biomass provisioning tables has progressed since this case study was undertaken. Please refer to the Guide v1 for the latest advice.

4.3.1 Fish nursery

Intent of work

A key service provided by coastal wetlands is the production of fish biomass. The mechanism for this service is the provision of 'nursery' habitat for juvenile fish and crustacean species. Typically, these are habitats where individuals experience increased growth rates and/or reduced mortality that ultimately results in elevated abundances of adult stages.

Approach taken

To quantify the nursery value of restored coastal wetlands we used densities of juvenile fish and crustaceans to model the number of individuals surviving through to adulthood. Adult densities were then converted to total biomass, based on species-specific length-at-age and length-weight relationships, to give an estimate of fish production (or 'nursery' value) on a per-unit-area basis. This can then be combined with the change in habitat extent to quantify the increase in fish production due to habitat restoration.

Results

Our analysis shows subtidal streams in Tomago wetland are responsible for the production of fish and crustacean biomass on the order of 103.6 kg ha^{-1} y^{-1}. This included a broad range of fish and crustaceans, that are harvested in estuarine (e.g. Dusky Flathead, *Platycephalus fuscus*) and nearshore oceanic habitats (e.g. Tailor, *Pomatomus saltatrix*, Eastern King Prawn, *Melicertus plebejus*). When considering the increase in areal extent of subtidal streams (45 ha), this equated to a total biomass enhancement of 4513.5 kg y^{-1}.

Reflection relevant to the Guide

Benefits from nursery habitats take some time to accrue, since it is only 'realized' when fish reach adulthood (or are old enough to be harvested). For some species, this does not take long (e.g. prawns) but for others it can take years (e.g. Australian Bass, *Macquaria novemaculata*), while the total benefit is not realized until the time since the restoration is greater than the maximum age of the longest-lived species. This means that knowledge of the species assemblage and the timescale of expected benefits from restoration is crucial when planning and evaluating a restoration project.

Introduction to nursery services

Coastal wetlands represent a mosaic of distinct habitats including seagrass, mangroves, and saltmarsh. One of the primary ecosystem services derived from these habitats is the support of fisheries production[97]. This is because many exploited species rely on these habitats for one (or more) life-history stages[98,99]. During juvenile stages, coastal wetlands may act as nursery habitats[100], conferring enhanced growth and survival[101], thereby supporting a disproportionate level of recruitment to adult (fished) populations[102].

Data available

There were no data on juvenile fish and crustacean densities available specifically for the Tomago restoration site. However long-term, pre- and post-restoration monitoring data are available from nearby Hexham wetland, and we use those as a proxy for Tomago. The Hexham wetland is also

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[97] Peterson, M. S. "A conceptual view of environment-habitat-production linkages in tidal river estuaries." *Reviews in Fisheries Science*, 11 (2003), 291-313. https://doi.org/10.1080/10641260390255844

[98] Abrantes, K., et al. "Habitat-specific food webs and trophic interactions supporting coastal-dependent fishery species: an Australian case study." *Reviews in Fish Biology and Fisheries*, 25 (2015), 337-363. https://doi.org/10.1007/s11160-015-9385-y

[99] Taylor, M. D., et al. "The role of connectivity and physicochemical conditions in effective habitat of two exploited penaeid species." *Ecological Indicators*, 80 (2017), 1-11. https://doi.org/10.1016/j.ecolind.2017.04.050

[100] Beck, M. W., et al. "The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates." *BioScience*, 51 (2001), 633-641. https://doi.org/10.1641/0006-3568(2001)051[0633:TICAMO]2.0.CO;2

[101] Haas, H. L., et al. "Brown Shrimp on the edge: Linking habitat to survival using an individual-based simulation model." *Ecological Applications*, 14 (2004), 1232-1247. https://doi.org/10.1890/03-5101

[102] Dahlgren, C. P., et al. "Marine nurseries and effective juvenile habitats: concepts and applications." *Marine Ecology Progress Series*, 312 (2006), 291-295. https://doi.org/10.3354/meps312291

within the Hunter River estuary and situated at a similar distance to the sea as the Tomago wetland, and bears similarities in abiotic conditions and community structure to the Tomago wetland[103,104]. In addition, we obtained animal life history parameters from published literature and NSW DPI Fisheries databases (**Table 4.13**).

Modelling biomass enhancement based on juvenile abundance

Hexham wetland is a Ramsar-listed wetland that covers ~2,000 ha in the lower Hunter River (NSW), approximately 8 km from the Tomago restoration site[105]. A series of 8 floodgates were installed on the main tributary to the swamp (Ironbark Creek) during the early 1970s as a flood mitigation strategy. This reduced tidal inundation of the wetland, which resulted in a transition from a mosaic of mangrove and saltmarsh habitats to predominantly freshwater vegetation (e.g. *Phragmites australis*) and pasture[105]. In turn, this reduced the abundance and diversity of juvenile fish and crustacean species[106], inhibiting the nursery function of this coastal wetland[107].

To rehabilitate coastal wetland habitats (i.e. mangroves, saltmarsh) and improve the nektonic assemblage at Hexham wetland, the staged opening of Ironbark Creek floodgates began in 2008. Over the course of 4 years (2008–2012), all 8 gates were opened, resulting in the reconnection of >320 ha of marsh habitat with the estuary[108]. Four years prior to the opening of the floodgates (2004), a long-term monitoring program was initiated to monitor the response of the nektonic assemblage[108].

As outlined above, there is no suitable data available to evaluate changes in abundance or density pre- and post-restoration in the Tomago wetland system. Given the similarities between these systems in terms of their abiotic conditions and distance from the estuary mouth, and similarities between the assemblages at these locations[108,109], we assumed that the differences in the density of aquatic taxa observed between the pre- and post-restoration periods in the Hexham wetland were indicative of changes that would have occurred in the Tomago wetland following re-introduction of connectivity. Coupled with changes in areal extent of waterway area in the Tomago wetland, this assumption formed the basis for the 'production enhancement' arising for the Tomago wetland restoration, as described below.

Sampling collection

Samples were collected in subtidal channels at Ironbark Creek during April, July, October, and December from 2004–2022. Samples were collected using four replicate seine-net hauls (10 m headline × 1.5 m drop × 3 mm stretch mesh[110]) spaced approximately 10 m apart, with a total swept area of ~85 m^2 (~0.008 ha) estimated using the approach in Wiryawan et al. (2017)[111]. Sampling began shortly before high tide and ended shortly after, to coincide with maximum depth and minimum velocity of tidal currents (i.e. 'slack' water)[112].

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[103] Boys, C. A. & B. Pease. "Opening the floodgates to the recovery of nektonic assemblages in a temperate coastal wetland." *Marine and Freshwater Research*, 68 (2016), 1023-1035. https://doi.org/10.1071/MF15445.

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[105 - 106] Winning, G. & N. Saintilan. "Vegetation changes in Hexham Swamp, Hunter River, New South Wales, since the construction of floodgates in 1971." *Cunninghamia*, 11 (2009), 185-194.

[107] Boys, C. A., & B. Pease. "Opening the floodgates to the recovery of nektonic assemblages in a temperate coastal wetland." Marine and Freshwater Research, 68 (2016), 1023-1035. https://doi.org/10.1071/MF15445

[108] McIlgorm, A., & J. Pepperell. "Developing a cost effective state wide expenditure survey method to measure the economic contribution of the recreational fishing sector in NSW in 2012." *University of Wollongong, Wollongong, NSW, Australia* (2013)

[109] Becker, A. & M. D Taylor. "Nocturnal sampling reveals usage patterns of intertidal marsh and subtidal creeks by penaeid shrimp and other nekton in south-eastern Australia." *Marine and Freshwater Research*, 68(7), 780-787 (2017). https://doi.org/10.1071/MF15325.

[110] Boys, C. A., & R. J Williams. "Succession of fish and crustacean assemblages following reinstatement of tidal flow in a temperate coastal wetland." Ecological Engineering, 49 (2012), 221-232. https://doi.org/10.1016/j.ecoleng.2012.08.006.

[111] Wiryawan, B., et al. "Characteristics of Beach Seine Fishery of East Java: Facing Ministerial Decree of Marine Affairs and Fisheries No. 2/2015." Research Journal of Life Science, 4 (2017), 67-75. http://dx.doi.org/10.21776/ub.rjls.2017.004.01.9.

[112] Boys, C. A., & B. Pease. "Opening the floodgates to the recovery of nektonic assemblages in a temperate coastal wetland." Marine and Freshwater Research, 68 (2016), 1023-1035. https://doi.org/10.1071/MF15445

Table 4.13: **Life history parameters for commercially harvested species sampled at Hexham wetland (NSW, Australia) used to model biomass enhancement at Tomago wetland (NSW, Australia).** *Continued over page.*

Species	Max. age (t_{max})	Natural mortality (M, year^{-1})	Asymptotic max. length (L_{∞}, cm)[b]	Brody growth coefficient (K, year^{-1})	Theoretical age at length = 0 (t_0)	a	b	$t_{harvest}$ (age of first harvest)	Source
Australian Anchovy *Engraulis australis*	7	0.82[a]	12.1	0.390	-0.5	0.0076	3.048	1	113
Australian Bass *Macquaria novemaculata*	22		50.8	0.166	-0.32	0.0071	3.091	5	114,115
Dusky Flathead *Platycephalus fuscus*									116
male	11	0.54[a]	43.2	0.714	-0.7	0.0029	3.223	3	
female	16	0.39[a]	127.6	0.084	-2.4	0.0021	3.283	3	
Eastern King Prawn *Melicertus plebejus*	2	2.40	5.5	2.400	0.0	0.0006	3.090	1	117
Flat-tail Mullet *Liza argentea*									118,119
male	12	0.50[a]	25.7	0.400	-0.97	0.0119	3.034	6	
female	17		29.7	0.330	-0.89				
Largehead Hairtail *Trichirus lepturus*									120
Male						0.0449	2.630	3	
Female	8	0.73[a]	18.9	0.128	-0.99	0.0172	2.891		

[113] Froese, R. & D. Pauly. "Fishbase (www database)." (2012), www.fishbase.org

[114] Wilde, G. R. & W. Sawynok, "Growth rate and mortality of Australian bass, *Macquaria novemaculeata*, in four freshwater impoundments in south-eastern Queensland, Australia." *Fisheries Management and Ecology*, 12(1) (2005). 1-7. https://doi.org/10.1111/j.1365-2400.2004.00412.x.

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[117] Courtney, A. J., et al. "Biological and economic management strategy evaluations of the eastern king prawn fishery." *Department of Agriculture, Fisheries, and Forestry, Queensland* (2014).

[118] Kendall, B. W., et al. "Age validation and variation in growth, mortality, and population structure of *Liza argentea* and *Myxus elongatus* (Mugilidae) in two temperate Australian estuaries." *Journal of Fish Biology*, 75 (2009), 2788-2804. https://doi.org/10.1111/j.1095-8649.2009.02485.x.

[119] NSW DPI (unpublished data).

[120] Clain, C. M. "Fishery demographics, biology, and habitat use of Hairtail (Trichirus lepturus) in south-eastern Australia." *Master of Philosophy (Science), Western Sydney University* (2020).

Species	Max. age (t_{max})	Natural mortality (M, year^{-1})	Asymptotic max. length (L_{∞}, cm)[b]	Brody growth coefficient (K, year^{-1})	Theoretical age at length = 0 (t_0)	a	b	$t_{harvest}$ (age of first harvest)	Source
Luderick *Girella tricuspidata*	16	0.39[a]	40.9	0.214	-0.75	0.0153	3.021	5	121
Sandy Sprat *Hyperlophus vittatus*	3	1.79[a]	7.8	1.830	0.0	0.0057	3.241	1	122,123
School Prawn *Metapenaeus macleaya*									
male	2	4.02	5.6	1.460	0.0	0.0005	2.930	1	124,125, 126
female	3	1.83	4.0	1.095	0.0	0.0005	2.930	1	
Tailor *Pomatomus saltatrix*	7	0.82[a]	141.7	0.070	-2.0	0.0103	3.082	2	127
Tarwhine *Rhabdosargus sarba*	16	0.41[a]	26.4	0.39	-0.56	0.0153	2.967	2	128,129
Yellowfin Bream *Acanthopagrus australis*	14	0.44[a]	29.5	0.510	-0.3	0.0281	2.933	3	130, 131

[a] Natural mortality (M) estimated based on maximum age (t_{max}) using the approach of Then (2014) [132]
[b] Refers to carapace length for crustaceans

[121] Pollock, B. R. "Age determination and growth of luderick, *Girella tricuspidata* (Quoy and Gaimard), taken from Moreton Bay, Australia." *Journal of Fish Biology*, 19 (1981), 475-485. https://doi.org/10.1111/j.1095-8649.1981.tb05850.x.

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[125] Hoenig, J. M. "Empirical use of longevity data to estimate mortality rates." *Fisheries Bulletin*, 81 (1983), 898-903.

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[128] Hughes, J. M., et al. "Growth and reproductive biology of tarwhine *Rhabdosargus sarba* (Sparidae) in eastern Australia." *Marine and Freshwater Research* 59(12) (2008), 1111-1123. https://doi.org/10.1071/MF08102.

[129] NSW DPI (unpublished data).

[130] Pollock, B. R. "Spawning period and growth of yellowfin bream, Acanthopagrus australis (Günther), in Moreton Bay, Australia." *Journal of fish Biology* 21 (3) (1982), 349-355. https://doi.org/10.1111/j.1095-8649.1982.tb02840.x.

[131] Carnell, P. E., et al. "Mapping Ocean Wealth Australia: The value of coastal wetlands to people and nature." The Nature Conservancy, Melbourne (2019).

[132] Then, A. Y., et al. "Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species." ICES Journal of Marine Science, 72 (2014), 82-92.

Estimating biomass enhancement

Juvenile (0.5 years old) densities ($D_{0.5}$; individuals ha^{-1}) from pre- and post-restoration time periods (pre-2008 and post-2008, respectively) were used to estimate biomass production in Hexham wetland (kg ha^{-1}) using the approach developed by Peterson et al.[133] and extended in Blandon and zu Ermgassen[134] and zu Ermgassen et al.[135]. To simplify notation, we have not included subscripts in the following formulas that specify species/sex, but calculations were applied to all species and sexes (where sex-specific parameters were available; **Table 4.13**). This approach estimates the density of individuals surviving to age class *i* ($D_{s,i}$) using the following equation:

$$D_i = D_{0.5} e^{-M \ (i-0.5)}$$

where $D_{E,0.5}$ is the previously measured density of juveniles and M is the natural mortality (**Table 4.13**). If no published estimates of natural mortality were available, it was estimated using the approach in Then et al.[136]:

$$M = 4.899 t_{max}^{-0.916}$$

where t_{max} is the maximum age for the species. Following this, the length of an average individual in each age class *i* (L_i; mm) was calculated using the von Bertalanffy growth equation:

$$L_i = L_\infty\left(1 - e^{(-K \ (i-t_0))}\right)$$

where $L\infty$ is the asymptotic maximum length, K is the Brody growth coefficient and t_0 is the theoretical age when length is 0 (**Table 4.13**). Lengths were then converted to weights (W_i; g) based on:

$$W_i = a \ L_i^b$$

where *a* and *b* are the intercept and slope, respectively, of the length-weight relationship (**Table 4.13**). Biomass in each year class *i* (B_i; g) was then calculated by:

$$B_i = W_i D_i$$

We then calculated the incremental increase in biomass between year classes (ΔB_i; g):

$$\Delta B_i = B_i - B_{i-1},$$

$$\Delta B_{i=t_{harvest}} = B_{i=t_{harvest}}$$

Where $t_{harvest}$ is the age of first harvest. From this, total harvestable biomass (HB; g ha^{-1} y^{-1}) was calculated by summing the incremental increase in weight between year classes from the age of first harvest to the maximum age (t_{max}):

$$HB = \sum_{i=t_{harvest}}^{t_{max}} \Delta B_i$$

Finally, enhancement of fish production due to restoration (E; g y^{-1}) was given by:

$$E = HB \Delta Area_{Tomago}$$

Where $\Delta Area_{Tomago}$ is the change in area (ha) of habitat due to restoration at Tomago wetlands. Given that most of the wetland system is high marsh that is infrequently inundated (see Becker and Taylor[137]), for this case study we regard subtidal streams (or 'waterbodies' under the extent account) as juvenile habitat. This is further justified by the fact that this is where the animals were sampled[138], where the biomass of aquatic taxa is 'concentrated' when the marsh surface is not inundated, and where they are primarily found in Tomago wetlands[139].

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133 Peterson, C. H., et al. "Estimated enhancement of fish production resulting from restoring oyster reef habitat: quantitative valuation." Marine Ecology Progress Series, 264 (2003), 249-264. https://doi.org/10.3354/meps264249.

134 Blandon, A., & P. S. E. zu Ermgassen. "Quantitative estimate of commercial fish enhancement by seagrass habitat in southern Australia." Estuarine, Coastal and Shelf Science, 141 (2014), 1-8. https://doi.org/10.1016/j.ecss.2014.01.009.

135 zu Ermgassen, P. S., et al. "Quantifying fish and mobile invertebrate production from a threatened nursery habitat." Journal of Applied Ecology, 53 (2016), 596-606. https://doi.org/10.1111/1365-2664.12576.

136 Then, A. Y., et al. "Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species." ICES Journal of Marine Science, 72 (2014), 82-92.

137 Becker, A., & M. D. Taylor. "Nocturnal sampling reveals usage patterns of intertidal marsh and subtidal creeks by penaeid shrimp and other nekton in south-eastern Australia." Marine and Freshwater Research, 68 (2017), 780-787. https://doi.org/10.1071/MF15325.

138 Boys, C. A., & B. Pease. "Opening the floodgates to the recovery of nektonic assemblages in a temperate coastal wetland." Marine and Freshwater Research, 68 (2016), 1023-1035. https://doi.org/10.1071/MF15445.

139 McIlgorm, A., & J. Pepperell. "Developing a cost effective state wide expenditure survey method to measure the economic contribution of the recreational fishing sector in NSW in 2012." University of Wollongong, Wollongong, NSW, Australia (2013).

Results

Restoration at Tomago wetland re-established connectivity between the wetlands and the Hunter River, where the commercial fishery operates. For this reason, we assumed that Tomago wetland was not providing any nursery service prior to restoration. However, our analysis shows that the nursery service provided by Tomago wetlands was significant post-restoration, providing nursery habitat for 15 commercially harvested species (Table 4.13). A lack of suitable life history parameters meant that 5 species were excluded from our modelling (i.e. Black Sole, *Brachiurus nigra*, Greasyback Prawn, *Metapenaeus bennettae*, Long-finned Eel, *Anguilla reinhardtii*, Short-finned Eel, *A. australis* and Small-toothed Flounder, *Pseudorhombus jenysii*).

Estimates of enhancement in fish production ranged from 0.09 kg y^{-1} for Australian Anchovy (*Engraulis australis*) to 14.733 kg y^{-1} for Sea Mullet (*M. cephalus*; Table 4.14). Cumulatively, the provision of nursery habitat within Tomago wetland is estimated to provide an additional 31,085 kg y^{-1} of harvestable fish and crustaceans (Table 4.14).

Table 4.14: Biomass enhancement of fish and crustacean species at Tomago wetland as result of increased area of subtidal streams (43.5 ha), modelled from juvenile densities in Hexham wetland (NSW, Australia).

Species	Juvenile densities in Hexham wetland (ind. ha^{-1} y^{-1})	Biomass production in Hexham wetland (kg ha^{-1} y^{-1})	Assumed biomass enhancement for Tomago wetland (kg y^{-1})
Australian Anchovy *Engraulis australis*	1.2	< 0.01	0.07
Australian Bass *Macquaria novemaculata*	9.4	0.07	3.09
Dusky Flathead[a] *Platycephalus fuscus*	3.5	0.29	12.70
Eastern King Prawn *Melicertus plebejus*	473.0	15.33	667.87
Flat-tail Mullet[a] *Liza argentea*	788.0	0.15	6.42
Largehead Hairtail[a] *Trichurus lepturus*	1.2	0.20	8.65
Luderick *Girella tricuspidata*	57.8	0.24	10.48
Sandy Sprat *Hyperlophus vittalus*	162.8	0.17	7.60
School Prawn[a] *Metapenaeus macleayi*	10,718.8	38.19	1,663.52
Tailor *Pomatomus saltatrix*	3.5	0.44	19.01
Tarwhine *Rhabdosargus sarba*	72.0	2.66	115.71
Yellowfin Bream *Acanthopagrus australis*	967.3	45.88	1,998.41

[a] Sex of juveniles was not recorded, and 1:1 sex-ratio was assumed for species with sex-specific parameter estimates.

Table 4.15: Post restoration ecosystem services supply in physical terms – supply table for year 2021.

Service type		Extent	Units	Coastal saltmarshes	Mangroves	Subtidal streams	Total supply
Regulating and maintenance services	Nursery population and habitat maintenance	Fish production	kg ha^{-1} y^{-1}	-	-	103.62	103.62
Provisioning services	Biomass provisioning	Wild commercial fisheries	kg ha^{-1} y^{-1}	155 (44)[a]	19 (7)[a]	-	174 (45)[a]

[a] values denote mean (± standard deviation).

Interpretation and discussion

In this case study, we have demonstrated how increasing juvenile habitat through habitat restoration can lead to the enhancement of harvestable biomass using a straightforward model of growth and survival[140,141]. Enhancement of juvenile densities as a function of habitat restoration is well documented in the Hunter River[142,143,144] and our analysis provides a link between early life stages and harvestable biomass that is crucial for the determination of the nursery value of a habitat[145,146]. Biomass enhancement was demonstrated across a broad range of demersal (e.g. Dusky Flathead, *Platycephalus fuscus*) and pelagic (e.g. Tailor, *Pomatomus saltatrix*) fish and crustaceans (e.g. Eastern King Prawn, *Melicertus plebejus*) that are harvested in both estuarine and nearshore oceanic waters. Biomass enhancement was exhibited by some of the most important harvested species in the Hunter River, ranging from ~2–16 % of the average total annual harvest (between 2005/06–2014/15) for School Prawn and Yellowfin Bream, respectively. This demonstrates the benefit habitat restoration may provide to commercial fisheries through increased production of harvestable biomass.

Of particular interest to decision makers is how the benefits of habitat restoration accrue over time. While our estimates biomass enhancement are reported as an annual figure (i.e. kg y^{-1}) these are only realized once the time since restoration is greater than the maximum age (tmax) of a given species, or the longest-lived species when considering the entire species assemblage (e.g. 22 years for Australian Bass; **Table 4.13**). However, in our example 99 % of the biomass enhancement for the entire species assemblage is realized after 6 years. On a species-by-species basis an additional consideration is the age of first harvest ($t_{harvest}$). For example, for fast-growing, species like prawns, 2–3 years is sufficient to realize the full biomass enhancement, while for most teleost fish species it is only after this period that individuals have attained a harvestable size and the benefits of habitat restoration begin to be realized.

[140] Blandon, A. S., & P. S. E. su Ermgassen. "Quantitative estimate of commercial fish enhancement by seagrass habitat in southern Australia." *Estuarine, Coastal and Shelf Science*, 141 (2014), 1-8. https://doi.org/10.1016/j.ecss.2014.01.009.

[141] zu Ermgassen, P. S. E., et al. "Quantifying fish and mobile invertebrate production from a threatened nursery habitat." *Journal of Applied Ecology*, 53 (2016), 596-606. https://doi.org/10.1111/1365-2664.12576.

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[145] Beck, M. W., et al. "The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates." *BioScience*, 51 (2001), 633-641. https://doi.org/10.1641/0006-3568(2001)051[0633:TICAMO]2.0.CO;2.

[146] Dahlgren, C. P., et al. "Marine nurseries and effective juvenile habitats: concepts and applications." *Marine Ecology Progress Series*, 312 (2006), 291-295. https://doi.org/10.3354/meps312291.

Typically, studies aimed at quantifying biomass enhancement have focused on structured habitats such as seagrass[147,148], oyster reefs[149], mangroves and saltmarsh[150], in some cases comparing them to unstructured 'control' sites[151,152]. In our approach, we assumed that subtidal streams were the primary nursery habitat for juvenile species. Primarily, this is because it is where the data were collected, and intertidal habitats in Tomago are only inundated and accessible to nekton infrequently[153]. However, it should be noted that all species included in this case study are mobile and may move between the habitats present. A more detailed approach may consider sampling within different coastal wetlands habitats with appropriate gear (and correcting for varying efficiency[154]).

It is important to note that the approach employed here assumes that fish production increases in a linear fashion with habitat extent. In New South Wales, coastal wetland habitats have experienced extreme reductions in their areal extent[155], so this assumption may hold in the early stages of restoration. However, at some point this relationship will reach an asymptote (i.e. 'level off') and other factors that influence fisheries productivity (e.g. recruitment) will begin to moderate the benefits of habitat restoration which are important to consider alongside the estimates provided here.

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[147] Blandon, A., & P. S. E zu Ermgassen. "Quantitative estimate of commercial fish enhancement by seagrass habitat in Southern Australia." *Estuarine, Coastal and Shelf Science*, 141 (2014), 1-8. https://doi.org/10.1016/j.ecss.2014.01.009.

[148] Jänes, H., et al. "Seagrass valuation from fish abundance, biomass, and recreational catch." *Ecological Indicators*, 130 (2021), 108097. https://doi.org/10.1016/j.ecolind.2021.108097.

[149] zu Ermgassen, P. S. E., et al. "Quantifying fish and mobile invertebrate production from a threatened nursery habitat." *Journal Of Applied Ecology*, 53 (2016), 596-606. https://doi.org/10.1111/1365-2664.12576.

[150] Jänes, H., et al. "Quantifying fisheries enhancement from coastal vegetated ecosystems." *Ecosystem Services*, 43 (2020), 101105. https://doi.org/10.1016/j.ecoser.2020.101105.

[151] Lindsey, A., & N. McNaughton. "Birds of Tomago Wetlands, Hunter Wetlands National Park 2007-2012." *The Whistler* (2012), 1-10.

[152] Huang, B., et al. "Quantifying welfare gains of coastal and estuarine ecosystem rehabilitation for recreational fisheries." *Science of The Total Environment*, 710 (2020), 134680. https://doi.org/10.1016/j.scitotenv.2019.134680.

[153] Becker, A., & M. D. Taylor. "Nocturnal sampling reveals usage patterns of intertidal marsh and subtidal creeks by penaeid shrimp and other nekton in south-eastern Australia." *Marine and Freshwater Research*, 68 (2017), 780-787. https://doi.org/10.1071/MF15325.

[154] Rozas, L. P., & T. J. Minello. "Estimating densities of small fishes and decapod crustaceans in shallow estuarine habitats: a review of sampling design with a focus on gear selection." *Estuaries*, 20(1997), 199-213. https://doi.org/10.2307/1352731.

[155] Rogers, K., et al. "Quantifying changes to historic fish habitat extent on north coast NSW floodplains, Australia." *Regional Environmental Change*, 16 (2015), 1469-1479. https://doi.org/10.1007/s10113-015-0872-4.

4.3.2 Fisheries biomass provisioning service

Intent of work

Primary production in coastal wetlands forms the basis of estuarine food webs and indirectly supports the growth of fish and crustaceans. This biomass provisioning supports the productivity of commercial fisheries, forming a key ecosystem service of coastal wetlands.

Approach taken

Published estimates of the proportional contribution of coastal wetlands (e.g. mangroves, saltmarsh) to the nutrition of commercially harvested fish and crustaceans were used in conjunction market and harvest data to determine the level and value of biomass provisioning provided by habitat restoration in Tomago wetland.

Results

Our analysis indicated that saltmarsh was responsible for most of the biomass provisioning in Tomago wetland, due to much higher contributions to the nutrition of commercially harvest species than mangroves. This discrepancy was exacerbated when considering the value of this biomass provisioning, since there was a significant increase in saltmarsh areal extent due to the restoration – a stated goal of the project. Furthermore, most of the value was derived from either high market value (e.g. Giant Mud Crab, *Scylla serrata*) or high harvest rate species (e.g. School Prawn, *Metapenaeus macleayi*).

Reflection relative to the Guide

Our analysis and results highlight the importance of considering the goal of restoration and species assemblage present within a proposed restoration site. For example, a restoration project aimed at mangrove habitat within an estuary that supports few important commercially harvest species may not yield significant benefits in terms of biomass provisioning for commercial fisheries relative to an equivalent saltmarsh restoration project.

Introduction to biomass provisioning

Coastal wetlands represent a mosaic of distinct habitats including seagrass, mangroves, and saltmarsh. One of the primary ecosystem services derived from these habitats is the support of fisheries production[156]. This is because coastal wetlands support high levels of primary production[157], forming the basis of coastal/estuarine food webs[158]. Transport of primary productivity within estuaries occurs over a range of spatial scales[159], from a few metres[160] to tens of kilometres[161]. Consequently, these habitats can provide a trophic subsidy for resident species and those that exhibit limited occupation of such habitats (e.g. penaeid prawns[162,163]).

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156 Peterson, M. S. "A conceptual view of environment-habitat-production linkages in tidal river estuaries." *Reviews in Fisheries Science*, 11 (2003), 291-313. https://doi.org/10.1007/s10750-006-0144-x.

157 Hyndes, G. A., et al. "Mechanisms and ecological role of carbon transfer within coastal seascapes." *Biological Reviews*, 89 (2014), 232-254. https://doi.org/10.1111/brv.12055.

158 Raoult, V., et al. "Habitat–fishery linkages in two major south-eastern Australian estuaries show that the C4 saltmarsh plant Sporobolus virginicus is a significant contributor to fisheries productivity." *Hydrobiologia*, 811 (2018), 221-238. https://doi.org/10.1007/s10750-017-3490-y.

159 Lindsey, A., & N. McNaughton. "Birds of Tomago Wetlands, Hunter Wetlands National Park 2007-2012." *The Whistler* (2012), 1-10.

160 Guest, M. A., & R. M. Connolly. "Fine-scale movement and assimilation of carbon in saltmarsh and mangrove habitat by resident animals." *Aquatic Ecology*, 38 (2004), 599-609. https://doi.org/10.1007/s10452-004-0442-1.

161 Gaston, T. F., et al. "Flood discharges of a small river into open coastal waters: Plume traits and material fate." *Estuarine Coastal and Shelf Science*, 69 (2006), 4-9. https://doi.org/10.1016/j.ecss.2006.03.01.

162 Becker, A., & M. D. Taylor. "Nocturnal sampling reveals usage patterns of intertidal marsh and subtidal creeks by penaeid shrimp and other nekton in south-eastern Australia." *Marine and Freshwater Research*, 68 (2017), 780-787. https://doi.org/10.1071/MF15325.

163 Hewitt, D. E., et al. "Stable isotopes reveal the importance of saltmarsh-derived nutrition for two exploited penaeid prawn species in a seagrass-dominated system." *Estuarine, Coastal and Shelf Science*, 236 (2020), 106622. https://doi.org/10.1016/j.ecss.2020.106622.

For this case study, we assess the biomass of commercially harvested species supported by restored coastal wetland habitats within the Hunter River. Specifically, this was achieved by 1) estimating the proportional contribution of coastal wetland habitats to the diet of commercially harvested species, and 2) using these estimates alongside commercial catch and fisheries economic data to apportion biomass supporting (physical account), and value arising from (monetary account), commercial fishing activities, among these habitats.

Data available

For this case study, we use previously published estimates of the proportional contribution of coastal wetland habitats to the diet of commercially harvested species[164] alongside commercial catch data to estimate the biomass (kg y^{-1}) supported by each habitat in the framework of Taylor et al. (2018)[165]. Economic information is then integrated to give an estimate of the overall value (AUD y^{-1}) of restoration activities in terms of commercial fishing[166].

Catch data was extracted from the NSW DPI Commercial Catch and Effort Reporting System (see https://www.dpi.nsw.gov.au/fishing/commercial/catch-effort), with annual harvest estimated on the basis of catch reporting for the period 2005/06–2014/15. Economic information included consumer price index (CPI) corrected Sydney Fish Market values across the same period (extracted from records compiled in the NSW DPI Resource Assessment System) and economic information published in Voyer et al. (2016)[167].

Estimating the proportional contribution of wetland habitats to the diet of exploited species

Raoult et al. (2018)[168] measured stable isotope ratios in coastal wetland habitats of Fullerton Cove and Fern Bay (adjacent to the Tomago restoration site) and applied a Bayesian mixing model to estimate the proportional contribution of wetland habitats to the diet of commercially exploited species. In the following, we briefly summarize the sample collection, preparation and analysis conducted in Raoult et al. (2018)[169].

Sample collection

Samples were collected from three sites within Fullerton Cove and Fern Bay, adjacent to the Tomago restoration site. All potential food sources for commercially harvested species were collected, including mangrove (*Avicennia marina*) leaves, mangrove pneumatophore epiphytes, fine benthic organic matter (FBOM–analogous to microphytobenthos, representing intertidal and subtidal mud banks lacking conspicuous vegetation), and the saltmarsh plants *Sporobolus virginicus* (Salt Couch), *Sarcocornia quinqueflora* (Beaded Samphire) and *Sueda australis* (Austral Seablite).

Fish and crustaceans were captured by commercial operators using standard mesh nets and traps in regions where effort is generally concentrated. The suite of species includes Eastern School Prawn (*Metapenaeus macleayi*), Blue Swimmer Crab (*Portunus armatus*), Giant Mud Crab (*Scylla serrata*), Yellowfin Bream (*Acanthopagrus australis*), Dusky Flathead (*Platycephalus fuscus*), Luderick (*Girella tricuspidata*), Sea Mullet (*Mugil cephalus*) and Mulloway (*Argyrosomus japonicus*). These species constitute approximately 85% of the commercially harvested biomass in the Hunter River[170].

[164] Lindsey, A. "The birds of Tomago Wetland after reinstatement of tidal flushing." *The Whistler* (2021), 6-26

[165] Taylor, M. D., et al. "The economic value of fisheries harvest supported by saltmarsh and mangrove productivity in two Australian estuaries." *Ecological Indicators*, 84 (2018), 701-709. https://doi.org/10.1016/j.ecolind.2017.08.044.

[166] McIlgorm, A., & J. Pepperell. "Developing a cost effective state wide expenditure survey method to measure the economic contribution of the recreational fishing sector in NSW in 2012." *University of Wollongong, Wollongong, NSW, Australia* (2013).

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[168 - 169] Raoult, V., et al. "Habitat–fishery linkages in two major south-eastern Australian estuaries show that the C4 saltmarsh plant *Sporobolus virginicus* is a significant contributor to fisheries productivity." *Hydrobiologia*, 811 (2018), 221-238. https://doi.org/10.1007/s10750-017-3490-y.

[170] Taylor, M. D., et al. "The economic value of fisheries harvest supported by saltmarsh and mangrove productivity in two Australian estuaries." *Ecological Indicators*, 84 (2018), 701-709. https://doi.org/10.1016/j.ecolind.2017.08.044.

Sample preparation

Raoult et al. (2018)[168] processed samples separately to avoid cross-contamination of isotopic signatures. For fishes, dorsal white muscle tissue was excised, while leg muscle was used for crabs and muscle from the abdomen was used for prawns. All samples were rinsed with distilled water to remove surface contaminants, placed in individual HCl-cleaned petri dishes and dried at 60°C for 24 h. Dried samples were ground to a fine powder for stable isotope analysis.

Stable isotope analysis was conducted at Griffith University (Queensland), using a Secron Hydra 20–22 automated Isoprime Isotope Ratio Mass Spectrometer. The standard used to compare isotope contents were Pee Dee Belemnite Limestone Carbonate for carbon and atmospheric nitrogen (i.e. air) for nitrogen. Stable isotope composition was expressed in delta-notation (δ) using conventional formulae[172].

Data analyses

All analyses were conducted using R (version 3.3.3) language for statistical computing[173]. The proportional contribution of coastal wetland habitats (hereafter "sources") to the diet of commercially harvested species (hereafter "consumers") was estimated using SIMMR[174] (available at https://github.com/andrewcparnell/simmr); an updated Bayesian mixing model, based on SIAR[175]. It was assumed that all sources were included in the analysis, and that there is complete mixing[176].

Raoult et al. (2018)[177] excluded δ15N from their analysis focusing only on δ13C signatures, since some sources were highly variable in terms of δ15N (e.g. FBOM), which would lower the likelihood of correctly estimating the proportional contributions of each source[178]. A generalized linear model (GLM) was used to pool sources that were not significantly different to each other and lower the number of sources modelled. This resulted in 3 sources: 'Mangrove + others' (comprised of *A. marina leaves* and pneumatophore epiphytes, *S. quinqueflora*, and *S. australis*), FBOM and *S. virginicus*.

The trophic enrichment factor (TEF) for δ13C was set to 1.0 ± 1.5 ‰ (mean ± SD;[179,180]). SIMMR does not directly incorporate consumer trophic levels in corrections for trophic enrichment; so TEFs were multiplied by the trophic level above that of the sources (assumed to = 1; Feng et al., 2014). Trophic levels of Eastern School Prawn, Blue Swimmer Crab, Giant Mud Crab, Yellowfin Bream, Dusky Flathead, Luderick, Sea Mullet, and Mulloway were assumed to be 2, 2, 2, 2.5, 2.5, 2, 2 and 3, respectively[181,182]. Concentration dependencies were not incorporated as elemental concentrations in FBOM were extremely diluted due to the presence of inorganic matter. Organic proportions were likely very low (~3 %) and incorporating concentration dependency would unrealistically inflate contributions of FBOM. The Gelman-Rubin diagnostic was used to assess convergence, where values close to 1 (i.e. < 1.05) are indicative of convergence[183,184].

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172 Fry, B. "Stable isotope ecology." *Springer Science + Business Media, LLC, Berlin*, (2006).

173 R Development Core Team. "R: A language and environment for statistical computing." *Vienna Austria: R Foundation for Statistical Computing* (2019).

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177 Raoult, V., et al. "Habitat–fishery linkages in two major south-eastern Australian estuaries show that the C4 saltmarsh plant Sporobolus virginicus is a significant contributor to fisheries productivity." *Hydrobiologia*, 811 (2018), 221-238. https://doi.org/10.1007/s10750-017-3490-y.

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181 Melville, A. J., & R. M Connolly. "Food webs supporting fish over subtropical mudflats are based on transported organic matter not in situ microalgae." *Marine Biology*, 148 (2005), 363-371. https://doi.org/10.1007/s00227-005-0083-5.

182 Hadwen, W., et al. "Gut content- and stable isotope-derived diets of four commercially and recreationally important fish species in two intermittently open estuaries." *Marine and Freshwater Research*, 58 (2007). https://doi.org/10.1071/MF06157.

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Apportioning economic benefits among coastal wetland habitats

The approach of Taylor et al. (2018)[185] was used to apportion commercially harvested biomass of consumers amongst coastal wetland habitats (i.e. mangrove, saltmarsh). Within this framework calculations were performed using a Monte Carlo simulation approach, whereby model parameters are randomly drawn from their respective distributions (Table 4.16) for n = 5,000 iterations.

To simplify notation, we have omitted subscripts that indicate species, however all subsequent calculations were applied to all species.

Table 4.16: Parameter distributions sampled during calculation of economic value of wetland habitats in our Monte Carlo simulations. Distributions are normal (*N*), log-normal (*LN*) or truncated-normal (*TN*) and defined according to their mean (μ), standard deviation (σ) and upper/lower bounds (0, 1) for the truncated-normal distribution.

Species	Saltmarsh contribution ($C_{s, saltmarsh}$), TN[μ, σ, 0, 1]	Mangrove contribution ($C_{s, mangrove}$), TN[μ, σ, 0, 1]	Annual landings (H_s; t y^{-1}), LN[μ, σ]	Market price (M_s; AUD kg^{-1}), N[μ, σ]	Spatial partitioning coefficient (P_s)
Blue Swimmer Crab *Portunus armatus*	0.576, 0.143	0.292, 0.154	1.6, 2.0	10.66, 1.17	0.70
Dusky Flathead *Platycephalus fuscus*	0.627, 0.083	0.166, 0.083	4.9, 1.7	10.29, 1.00	0.80
Giant Mud Crab *Scylla serrata*	0.456, 0.057	0.241, 0.018	12.1, 0.8	29.3, 2.72	0.80
Luderick *Girella tricuspidata*	0.400, 0.010	0.350, 0.174	4.0, 0.8	2.16, 0.31	0.90
Mulloway *Argyrosomus japonicus*	0.465, 0.047	0.175, 0.078	5.1, 2.5	11.10, 0.91	0.85
School Prawn *Metapenaeus macleayi*	0.474, 0.060	0.208, 0.100	54.5, 24.3	10.29, 1.00	1.00
Sea Mullet *Mugil cephalus*	0.533, 0.108	0.200, 0.106	69.5, 31.7	3.74, 0.22	0.50
Yellowfin Bream *Acanthopagrus australis*	0.316, 0.080	0.292, 0.154	8.5, 2.3	13.24, 0.77	0.80

185 Taylor, M. D., et al. "The economic value of fisheries harvest supported by saltmarsh and mangrove productivity in two Australian estuaries." *Ecological Indicators*, 84 (2018), 701-709. https://doi.org/10.1016/j.ecolind.2017.08.044.

Biomass provisioning (B_h, s; kg y^{-1}) from habitat *h* was estimated using the following formula:

$$B_{h,s} = C_{h,s}H_s$$

where $C_{h,s}$ is the estimated proportional contribution of habitat *h* to species *s* (based on the Bayesian mixing model) and H_s is the annual harvest of species *s* (kg y^{-1}). This value is then used to calculate the gross value of product derived from habitat *h* to species *s* ($GVP_{h,s}$; AUD y^{-1}) using the following formula:

$$GVP_{h,s} = B_{h,s}M_sP_s$$

where M_s is the consumer price index corrected market value at first-point-of-sale (AUD kg^{-1}) and P_s is a fixed spatial partitioning coefficient. The spatial partitioning coefficient reflects a subjective estimate of the average proportion of total harvest that is taken within the modelled region. This parameter is included to account for the relevant section of the estuary used by species *s*, effectively constraining our estimates of $GVP_{h,s}$. For each species, P_s was informed via expert opinion and consultation with fishers and fisheries compliance officers regarding the distribution of catch and effort within the Hunter River[186]. Catch data was extracted from the NSW DPI Commercial Catch and Effort Reporting System (see https://www.dpi.nsw.gov.au/fishing/commercial/catch-effort), with annual harvest estimated on the basis of catch reporting for the period 2005/06–2014/15. Market price was estimated from CPI-corrected Sydney Fish Market values across the same period (extracted from records compiled in the NSW DPI Resource Assessment System).

From GVP_h we estimated the ecosystem service value of habitat h (ESV_h) by deducting direct operational costs (*OC*) of fishing estimated for New South Wales estuarine fishing (52 % of revenue) reported in Voyer et al.[187]:

$$ESV_h = GVP_h(1 - \frac{OC}{100})$$

To account for expected flow-on economic benefits of commercial fishing (e.g. retail and processing output) we estimated total economic output for habitat *h* ($TEO_{h,}$) using the following formula:

$$TEO_{h,s} = GVP_{h,s}m$$

where *m* (**N**[μ, σ]) represents an economic multiplier, derived from the relationship between statewide-GVP for New South Wales (GVP_{NSW}, AUDm79.44), and the minimum (TEO_{min}; AUDm436.13) and maximum (TEO_{max}; AUDm501.24) estimates of total economic output from commercial fishing reported in [187]. Thus, *m* was estimated as **N**[5.90, 0.14] according to:

$$\sigma = \frac{TEO_{max} - TEO_{min}}{6GVP_{NSW}}$$

$$\mu = \frac{TEO_{max}}{GVP_{NSW}} - 3\sigma$$

For each habitat *h*, biomass provisioning (B_h), gross value of product GVP_h, ecosystem service value (ESV_h) and total economic output (TEO_h) were summed across all species to give their cumulative value (GVP_h and TEO_h, respectively) which was then divided by the areal extent (ha) of habitat h within the model region to give habitat-specific estimates on a per-hectare basis (i.e. kg ha^{-1} y^{-1} and AUD ha^{-1} y^{-1}). Finally, these values were multiplied by the total area of habitat *h* (ha) within Tomago wetlands to obtain an estimate of their increase as a function of habitat restoration. We used the total area of habitat within Tomago wetlands as restoration at this site re-established connectivity between the wetland and the Hunter River (where fishing takes place) which is a pre-requisite for the biomass provisioning service. As such, we assumed that this service was not being provided pre-restoration.

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[186] Taylor, M. D., et al. "The economic value of fisheries harvest supported by saltmarsh and mangrove productivity in two Australian estuaries." *Ecological Indicators*, 84 (2018), 701-709. https://doi.org/10.1016/j.ecolind.2017.08.044.

[187] Voyer, M., et al. "Social and economic evaluation of NSW coastal professional wild-catch fisheries: valuing coastal fisheries." *Fisheries Research and Development Corporation* (2016).

Results

On average, saltmarsh (*S. virginicus*) supported greater biomass provisioning (1.79–36.36 kg ha^{-1} y^{-1}) than mangrove habitats (0.17–4.25 kg ha^{-1} y^{-1}) within the modelled region. Consequently, the monetary value of saltmarsh was much greater than mangroves. When considering the area of saltmarsh and mangrove habitats reconnected to the Hunter River as a result of habitat restoration, this resulted in significant biomass provisioning (in both physical and monetary terms). On average, physical biomass provisioning ranged between 247–5,015 kg y^{-1} for saltmarsh and 0.66–16.84 kg y^{-1} for mangroves, depending on species (**Table 4.16**). Cumulatively, this amounts to 13,511 (± 3,462) kg y^{-1} and 47.90 kg y^{-1}, respectively (**Table 4.16**). The cumulative ecosystem service value for saltmarsh and mangrove habitats was estimated to be AUD 61K (± 26 K) y^{-1} and AUD 228 (± 130) y^{-1}, respectively (**Table 4.17**). The estimated gross revenue associated with this ecosystem service was approximately twice the ecosystem service value (**Table 4.17**) since direct operating costs are ~50 % in the NSW estuarine fishery[187]. However, when considering the total economic output associated with this service (which includes retail and processing output), cumulative estimates of value range from AUD 2.8K (± 775) y^{-1} for mangroves to AUD 756 (± 158 K) y^{-1} for saltmarsh (**Table 4.17**).

The large discrepancy between the two habitat types is a function of the comparatively small areal coverage of saltmarsh (509 ha) relative to mangroves (1,908 ha) within the model region, relatively high proportional contributions of saltmarsh to the diet of commercially harvested species (0.316–0.627; **Table 4.15**) and the vast increase in saltmarsh due to restoration (**Table 3.2**).

Table 4.17: Mean (± SD) estimated increase in biomass provisioning (kg y-1) from Tomago wetland post-restoration for commercially harvested species in the Hunter River (NSW).

Species	Saltmarsh biomass provisioning (kg y^{-1})	Mangrove biomass provisioning (kg y^{-1})
Blue Swimmer Crab[a] *Portunus armatus*	247.00 (306.64)	0.66 (1.00)
Dusky Flathead *Platycephalus fuscus*	663.47 (253.79)	1.38 (0.83)
Giant Mud Crab *Scylla serrata*	1,198.36 (166.99)	4.84 (0.48)
Luderick *Girella tricuspidata*	392.23 (79.18)	2.68 (1.34)
Mulloway *Argyrosomus japonicus*	554.23 (312.54)	1.63 (1.11)
School Prawn *Metapenaeus macleayi*	4,852.54 (2,195.87)	16.84 (11.14)
Sea Mullet *Mugil cephalus*	5,015.90 (2612.38)	15.59 (10.97)
Yellowfin Bream *Acanthopagrus australis*	587.73 (226.12)	4.28 (2.36)
Cumulative biomass (kg y^{-1})	13,511.46 (3,462.34)	47.90 (15.97)

[a] Note that estimated values must be positive and estimates where SD > mean is indicative of positive (upper-tail) skew.

[188] Jänes, H., et al. "Stable isotopes infer the value of Australia's coastal vegetated ecosystems from fisheries." *Fish and Fisheries*, 21(1) (2020), 80-90. https://doi.org/10.1111/faf.12416.

For fish species, the highest values for saltmarsh and mangroves are derived from Sea Mullet and Yellowfin Bream, while Luderick accounts for the least (**Table 4.18**). When considering crustaceans, Eastern School Prawn accounts for approximately 1.3 times the value of Giant Mud Crab and Blue Swimmer Crab combined (**Table 4.18**; **Table 4.19**). On a species-by-species basis, patterns in value are primarily driven by differences in market value and annual landings, with the level of provisioning support having a smaller effect on the simulations. For example, Yellowfin Bream is a much higher value species (AUD 13.24 ± 0.77 kg^{-1}) than Sea Mullet (AUD 3.74 ± 0.22 kg^{-1}; **Table 4.16**) however, this is outweighed by much greater annual landings of the latter (**Table 4.18**). Similarly, Eastern School Prawn is a much lower value species than Giant Mud Crab (**Table 4.16**) but is harvested at approximately 4.5 times greater quantities leading to a much higher overall valuation (**Table 4.18**).

Table 4.18: **Mean (± SD) estimated increase in service value (AUD y^{-1}), gross value of product (GVP; AUD y^{-1}) and total economic output (TEO; AUD y^{-1}) from Tomago wetland post-restoration for commercially harvested species in the Hunter River (NSW).**

	Saltmarsh			Mangrove		
Species	Service	GVP	TEO	Service	GVP	TEO
Blue Swimmer Crab[a] *Portunus armatus*	1,262.20 (1,577.49)	2,629.59 (3,286.45)	15,514.66 (19,359.26)	3.39 (5.17)	7.06 (10.78)	41.69 (63.44)
Dusky Flathead *Platycephalus fuscus*	3,270.72 (1,293.44)	6,814.00 (2,694.66)	40,250.25 (15,964.00)	6.78 (4.14)	14.12 (8.62)	83.32 (50.90)
Giant Mud Crab *Scylla serrata*	16,845.43 (2,856.90)	35094.65 (5,951.88)	207,144.11 (35,529.69)	67.94 (9.18)	141.53 (19.12)	835.44 (114.69)
Luderick *Girella tricuspidate*	407.52 (101.86)	849.00 (212.20)	5,011.46 (1,256.72)	2.79 (1.47)	5.81 (3.05)	34.27 (18.07)
Mulloway *Argyrosomus japonicus*	2,960.28 (1678.12)	6,167.25 (3,496.08)	36,404.48 (20,577.85)	8.69 (5.99)	18.11 (12.48)	106.90 (73.74)
School Prawn *Metapenaeus macleaya*	23,998.53 (11,196.29)	49,996.94 (23,325.60)	295,228.19 (138,173.65)	83.27 (56.22)	173.47 (117.12)	1,025.06 (693.26)
Sea Mullet *Mugil cephalus*	8,984.48 (4,709.59)	18,717.66 (9,811.64)	110,609.33 (58,192.62)	27.94 (19.78)	58.21 (41.21)	343.83 (243.56)
Yellowfin Bream *Acanthopagrus australis*	3,735.30 (1,455.45)	7,781.88 (3,032.19)	45,942.17 (17,958.25)	27.23 (15.12)	56.73 (31.51)	335.03 (186.61)
Cumulative value (AUD y^{-1})	61,464.46 (26,475.10)	128,050.97 (26,745.10)	756,104.70 (158,486.10)	228.03 (130.88)	475.04 (130.88)	2,805.5 (774.78)

[a] Note that estimated values must be positive and estimates where SD > mean is indicative of positive (upper-tail) skew.

Table 4.19: Post restoration ecosystem services supply in monetary terms – supply table for year 2021.

Service type		Extent	Units	Coastal saltmarshes	Mangroves	Subtidal streams	Total supply
Provisioning services	Biomass provisioning	Wild commercial fisheries	AUD ha^{-1} y^{-1}	928 (194)[a]	120 (33)[a]	-	1,048 (197)[a]

[a] values denote mean (± standard deviation).

Interpretation and discussion

In this case study, we have demonstrated how estimates of the dietary contributions of coastal wetlands to commercially harvested species can be used alongside catch and economic information to apportion commercial fisheries harvest (kg ha^{-1} y^{-1}) and economic value (AUD ha^{-1} y^{-1}) among these habitats. Overall, the value of saltmarsh (*S. virginicus*) far outweighed that of mangroves, primarily due to making much higher contributions to the diet of the species examined[189]. This may be due to greater 'biological availability' as a result of faster decomposition[190] and growth[191] of saltmarsh relative to mangroves[192] coupled with the 'toughness' of mangroves leaves with their waxy cuticle[193].

In our analysis, most of the value derived from habitat restoration was realized through three species: Giant Mud Crab, School Prawn and Sea Mullet. For Giant Mud Crab, this is primarily a function of high market value for the species, while for the other two extremely high harvest rates are responsible for this. This highlights how fisheries dynamics (e.g. fisher behaviour) and market forces can also influence the benefits of restoration.

The analysis employed here assumes that the productivity of fisheries is habitat limited. That is, that an increase in habitat will result in a 1:1 increase in fisheries productivity. In New South Wales, coastal wetland habitats have experienced extreme reductions in their areal extent[194], so this assumption may hold in the early stages of restoration. However, at some point this relationship will reach an asymptote (i.e. 'level off') and other factors that influence fisheries productivity will begin to moderate the benefits of habitat restoration which it is important to consider alongside the estimates provided here. Population processes, such as recruitment, have clear implications for limiting fisheries productivity. For example, spawning in Giant Mud Crab is linked to patterns in river flow[195] and subsequent recruitment of larvae is mediated by patterns in oceanic circulation[196] which may also influence patterns in harvest. Thus, rainfall and oceanic circulation limit the number of recruits available to make use of the enhanced provisioning derived from habitat restoration. Additional factors, such as density-dependence, predator-prey dynamics and fisher behaviour can also influence fisheries productivity.

189 Raoult, V., et al. "Habitat–fishery linkages in two major south-eastern Australian estuaries show that the C4 saltmarsh plant *Sporobolus virginicus* is a significant contributor to fisheries productivity." *Hydrobiologia*, 811 (2018), 221-238. https://doi.org/10.1007/s10750-017-3490-y.

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191 Linthurst, R. A., & R. J. Reimold. "Estimated net aerial primary productivity for selected estuarine angiosperms in Maine, Delaware, and Georgia." *Ecology*, 59 (1978), 945-955. https://doi.org/10.2307/1938546.

192 Komiyama, A., et al. "Allometry, biomass, and productivity of mangrove forests: A review." *Aquatic Botany*, 89 (2008), 128-137. https://doi.org/10.1016/j.aquabot.2007.12.006.

193 Choong, M., et al. "Leaf fracture toughness and sclerophylly: their correlations and ecological implications." *New Phytologist*, 121 (1992), 597-610. https://doi.org/10.1111/j.1469-8137.1992.tb01131.x.

194 Rogers, K., et al. "Quantifying changes to historic fish habitat extent on north coast NSW floodplains, Australia." *Regional Environmental Change*, 16 (2015), 1469-1479. https://doi.org/10.1007/s10113-015-0872-4.

195 Hewitt, D. E., et al. "Crabs go with the flow: Declining conductivity and cooler temperatures trigger spawning migrations for female Giant Mud Crabs (Scylla serrata) in subtropical estuaries." *Estuaries and Coasts*, 45 (2022), 2166-2180. https://doi.org/10.1007/s12237-022-01061-1.

196 Hewitt, D. E., et al. "Mesoscale oceanographic features drive divergent patterns in connectivity for co-occurring estuarine portunid crabs." *Fisheries Oceanography*, 31 (2022), 587-600. https://doi.org/10.1111/fog.12608.

4.4 Regulation and maintenance

4.4.1 Carbon stocks, sequestration & emissions

Intent of work

This section details an integrated approach for quantifying two related but distinct accounts associated with greenhouse gas regulation service provision: *carbon abatement* and *carbon stocks*. The *carbon abatement* account integrates estimates of greenhouse gas emissions and sequestration through the life of the Tomago restoration project (2007 to 2022) to determine the net outcomes of *carbon abatement* of tidal restoration actions at this site. This account includes both physical and financial accounts.

In contrast, the *carbon stock* account provides snapshots of the amount of carbon stored in above ground biomass and soil carbon (to 1 m depth) pools within the Tomago study area, estimated at two time points: a pre-restoration time point (2007) and a post-restoration time point (2022). No financial account has been estimated for *carbon stocks* as this would represent a double-counting of values which are already considered in the *carbon abatement* account.

Approach taken

The data-rich nature of the Hunter estuary setting for carbon cycling parameters (relative to many other settings in Australia) allows for the demonstration of three complementary approaches for accounting for carbon services at Tomago. These tiers are:

- a nationally-consistent approach which utilizes nationally-available datasets only;
- a detailed approach which utilizes high resolution imagery and water level data;
- a more detailed approach which applies tier (B) approach, with the addition of setting-specific carbon data from the Hunter estuary and associated settings.

The Blue Carbon Accounting Model (BlueCAM) calculator is a foundational tool in the development of physical accounts for both carbon abatement and carbon stocks under each of the above tiers. Tables provided in the detailed **Section 4.4** outline the inputs which have been used in each version (tier) of BlueCAM calculator operation. The delineation of specific Carbon Estimation Areas (CEAs) within a project area, and their parameterization in BlueCAM is an important step in this process. Details are also provided on how BlueCAM outputs were compiled to derive final accounts for *carbon abatement* (physical account plus financial account) and *carbon stocks* (physical account only).

Accounts are provided in both the BlueCAM framework (carbon abatement and carbon stocks) in this section, and aligning with the SEEA framework ('storage' and 'sequestration') in Section 9.

Results

The outcomes of carbon abatement and carbon stock accounts are presented at the scale of individual CEAs and at the overall Tomago project scale. These results show large variations associated with the choice of accounting approach and detail (i.e. tiers A, B and C above) shows large variation among methodologies. Overall abatement and stock estimates were ~30% and ~100% higher, respectively, in the 'detailed approach' (B) and 'detailed approach with setting-specific data' (C), than the nationally-consistent approach (A).

Depending on the accounting approach taken, estimates of carbon abatement volume across the 16 years since tidal restoration at Tomago range from 7,357 to 14,800 t CO2e. This volume of abatement equates to the annual electricity emissions of approximately 1,431 to 2,880 households, or 122,000– 245,000 tree seedlings grown for 10 years[197].

The *carbon stock* accounts demonstrate the substantial amount of carbon stored within the coastal wetlands of the Tomago site. Stock estimates were high (>90,000 t CO_2e) in both

[197] United States Environmental Protection Agency. "Greenhouse Gas Equivalencies Calculator." https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator. (Accessed March 29, 2023).

baseline (2007) and project (2022) accounts under all approaches, and as high as 294,352 t CO_2e in the highest case project scenario (**Table 4.30**). These stock estimates equate to the to the annual electricity emissions of approximately 17,700 to 57,300 households, or the amount of carbon sequestered by growing 1.5 to 4.9 million tree seedlings for 10 years[198]. This finding demonstrates the carbon-rich nature of the Tomago setting, and the significant amount of carbon which may be at risk of emission to the atmosphere if the site is disturbed or restoration practices are reversed.

Reflection relative to the Guide

The incorporation of three tiers of accounting approach in this case study provides a detailed example of various ways in which carbon accounts may be applied under the Guide. The increase in overall carbon abatement and carbon stock accounts when using the most detailed approach highlights the significance of applying setting-specific datasets in concert with the BlueCAM framework, in carbon accounts. While the Tomago case study had access to setting-specific parameters for some land types and some specific carbon cycling parameters, there remain significant data gaps across all ecosystem/land cover types and across all carbon parameters (i.e. biomass, soil carbon, CH_4 and N_2O fluxes) which prevented more accurate determination of the true abatement and stock outcomes of the Tomago restoration project.

Introduction to quantifying greenhouse gas regulation

This section details an integrated approach for quantifying two related but distinct accounts associated with greenhouse gas regulation service provision:

- *Carbon abatement* (Avoided Emissions, Emissions and Sequestration): Physical AND Financial Accounts
- *Carbon stocks* (aboveground biomass stocks, soil carbon stocks to 1 m): Physical Accounts only

Accurate estimation of the carbon abatement outcomes of a restoration project requires consideration of multiple greenhouse gas fluxes related to the activity, over a relevant time period. These greenhouse gas fluxes include any emissions which would have been expected from the project area if the restoration project had not occurred (termed 'avoided emissions'); any direct or indirect emissions resulting from the restoration activity itself; and any additional sequestration in biomass and soil carbon pools resulting from the restoration activity. Accurate estimation of the overall carbon abatement outcome of a restoration project therefore needs to consider the net direction and magnitude of these combined fluxes over the entire accounting period.

Accurate estimation of the carbon stock outcomes of a restoration project requires consideration of any change in significant carbon pools (in this instance: aboveground biomass carbon pool, and soil carbon pool to 1m depth) resulting from the restoration activity, over a relevant time period.

The geographic extent of carbon abatement and carbon stock estimation may change over time, due to the dynamic nature of coastal ecosystems, and the potential for both eustatic sea-level rise and any modification of engineering controls to alter inundation footprints and therefore, the spatial extent of physical and biotic controls on carbon cycling. Blue carbon projects under the Australian Carbon Credit Units would typically be required to account for carbon abatement not only within contemporary project boundaries, but also over land that will be within the intertidal zone in 100 years (i.e. land that is within the elevation envelope of the highest astronomical tide with anticipated levels of sea level rise). As the current project seeks only to quantify carbon abatement over the period 2007-2022, the Tomago restoration project area extent identified in **Section 3.1** is suitable for EEA purposes, and will therefore be used to provide consistency with other service accounts.

[198] United States Environmental Protection Agency. "Greenhouse Gas Equivalencies Calculator." https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator. (Accessed March 29, 2023).

Table 4.20: Summary of three tiers of approach demonstrated in the Tomago restoration project case study for both carbon abatement and carbon stock accounts.

Approach	Datasets used	Expected outcome
(A) Nationally-consistent approach	– Nationally-consistent extent accounts (Section 3) – Nationally-consistent tide gauge approach – Nationally-available elevation dataset – Modified version of BlueCAM calculator with additional outputs for EEA projects	Low site-specificity > less reliable account
(B) Detailed approach	– Detailed approach extent accounts (Section 3) – Site-specific tide gauge approach – Nationally-available elevation dataset – Modified version of BlueCAM calculator with additional outputs for EEA projects	Moderate site-specificity > moderately reliable account
(C) Detailed approach with setting-specific carbon data	– Detailed approach extent accounts (Section 3) – Site-specific tide gauge approach – Nationally-available elevation dataset – Site-specific (Tomago) and setting-specific (Hunter estuary and nearby sites) blue carbon datasets, from published and unpublished sources – Modified version of BlueCAM calculator with additional outputs for EEA projects	High site-specificity > highly reliable account

Data availability

The Hunter estuary provides an excellent example of a project-level EEA with multiple existing datasets which can be used to inform accounting of both *carbon abatement* and *carbon stocks*. For this case study, three different carbon accounting approaches ranging from low to high site-specificity are demonstrated as detailed in **Table 4.20**.

Methods

Blue Carbon Accounting Model (BlueCAM) calculator:

The Blue Carbon Accounting Model (BlueCAM) calculator is a foundational tool in the development of physical accounts for both *carbon abatement* and *carbon stocks* under this Guide. The methodology for all three tiers of approach (A, B and C in table above) utilises the BlueCAM calculator, and these approaches broadly follow the requirements of the following BlueCAM guidance documents and scientific outputs:

- ACCU Method Guide
- Blue Carbon Accounting Model (BlueCAM) Guidelines
- Blue Carbon Accounting Model (BlueCAM) Technical Overview

In some instances minor variations from these guidance documents are implemented in the Tomago EEA case study, for the following reasons: (1) provide greater simplicity for higher level EEA assessments (i.e. as opposed to ACCU projects); (2) ensure consistency with other physical and financial accounts quantified in the case study; and (3) enable use of setting-specific datasets in the detailed approach (i.e. approach 'C'). The rationale for such variations from BlueCAM guidance is provided in this section and tables below.

Note: A single file of the publicly-available BlueCAM calculator file can be used to generate all required outputs for the *carbon abatement* account. This public version of the calculator, however, does not provide the outputs required for the *carbon stock* account – in this instance an additional, modified version of BlueCAM for EEA purposes is required.

BlueCAM inputs:

Operation of BlueCAM for both *carbon abatement* and *carbon stock* accounting purposes requires two types of data inputs: (1) project level parameters; and (2) Carbon Estimation Area (CEA) parameters.

Project level parameters include project accounting timeframes, the tidal range of the project site, and quantification of any fuel use associated with the project. The source of these project level parameter inputs, and rationale for their use for the Tomago restoration project is detailed in **Table 4.21**.

Accurate carbon abatement accounting may require the stratification of the project area into sub-units (termed Carbon Estimation Areas or CEAs in BlueCAM). For BlueCAM, CEAs may need to be delineated within a project area on the basis of different land-uses, vegetation types and levels of land elevation (relative to Australian Height Datum or m AHD) – factors which may all change for a given parcel of land over the life of a project. While ACCU projects are typically required to monitor and delineate CEAs at multiple intervals (e.g. every five years) over the life of a project, carbon abatement accounting for the Tomago EEA project utilises a simplified approach. That is, CEAs are delineated on the basis of two timepoints: a CEA baseline land type based upon status prior to 2007; and reporting period (post-restoration) status in 2022. The source of CEA parameter inputs, and rationale for their use for the Tomago restoration project is detailed in **Table 4.21**. Further guidance on the definition of CEA land types is provided in ACCU technical documents.

Spatial analyses were undertaken to determine the number, type and extent of each CEA, with separate analyses required for the national approach (A) and the detailed approaches (B and C were completed together). In each instance, relevant ecosystem extent maps for CEA baseline land type in 2007 and post-restoration land type in 2022 (column headers) were used as inputs in a 'change detection analysis'. This returned a new raster layer depicting the extent of each category of land type change within the project area. As the land types defined by the extent account approaches do not align perfectly with the prescribed land type inputs available in BlueCAM, a harmonization process was required whereby input land classes were converted to the most suitable BlueCAM value (**Table 4.22**).

The elevation of a CEA operates as a modifier of some carbon cycling parameters in BlueCAM. To determine the elevation of each CEA, a further spatial analysis was undertaken for each of the national (A) and detailed (B & C) approaches. That is, the land type change raster described above was first converted to multipart polygon files, and a zonal statistics tool was used to compute central estimates of elevation for each polygon/CEA, using a high-resolution digital elevation model (**Table 4.21**). Both median and mean elevation values for each CEA are reported in **Table 4.23**, with the median value used in BlueCAM to minimize the influence of any elevation outliers.

Finalised Project level parameters and CEA input parameters were entered into a 'subtropical' BlueCAM worksheet following specifications outlined for nationally-consistent (A) and detailed (B and C) approaches in **Table 4.20** and **Table 4.21**.

A further process was undertaken for the final detailed approach (C) to replace generic BlueCAM model parameters with site- and setting-specific parameters identified in published literature and available, unpublished datasets (**Table 4.25**). These new values (and the BlueCAM values they replace) are detailed in **Table 4.26**.

BlueCAM outputs (physical accounts):

Carbon abatement: Two sets of outputs were derived from BlueCAM calculator to populate carbon abatement accounts tables. There are: (1) estimates of carbon abatement parameters for each individual CEA (**Table 4.24**, populated from BlueCAM calculator rows AC, AG and AM), and (2) (**Table 4.25**, populated from BlueCAM calculator cells AQ3: AT3). Note that BlueCAM automatically applies at 5% reduction on the overall abatement estimate (i.e. Net abatement amount (A_r)) within the BlueCAM calculator (i.e. cell AT3). This discount is a specific requirement of projects seeking carbon credits under the tidal restoration method of Australian Carbon Credit Units (ACCUs), but is less relevant to ACCU projects which are not operating under this system. For this reason, **Table 4.25** includes an additional row 'Net abatement amount ($A_{r\text{-}adj}$): ACCU discount removed', whereby $A_{r\text{-}adj}$ is the net sum of values E_A, CP and E_{fk} (i.e. no 5 % discount applied).

Carbon stocks: Four carbon stock values were derived separately for each of the three tiers of approach (i.e. scenario (i.e. approaches A, B and C detailed above). These stocks, and the way in which they were derived from BlueCAM files are defined in **Table 4.27**.

SEEA accounts:

Physical accounts of carbon stocks (termed 'storage' under the SEEA framework) for opening and closing periods were transferred from the pre-restoration (2006) and post-restoration (2022) BlueCAM outputs which are reported in n **Table 4.29**.

The BlueCAM approaches described in the sections above do not provide opening and closing sequestration accounts, which are required by the SEEA framework. An additional approach was therefore undertaken whereby two further BlueCAM model runs were undertaken: (1) a simulation of a single year prior to commencement of restoration (i.e. 2006) and (2) a simulation of a single year at the end of the post-restoration accounting period (i.e. 2022). Inputs for each of these additional simulations followed CEA parameters relevant to baseline (2006) and end of project (2022) scenarios, respectively.

This SEEA approach for sequestration does not incorporate avoided emissions and therefore is not reflective of the overall carbon abatement of the restoration project. For detailed accounts of the overall carbon abatement outcomes, see the BlueCAM derived accounts in the current section.

For both 'storage' and 'sequestration', SEEA accounts were populated using estimates generated under the '(C) Detailed approach with setting-specific carbon data', as this is considered the most accurate accounting approach for the site.

Results

Table 4.28 details the *carbon abatement* outcomes over the entire restoration accounting period (2007 to 2022), as well as baseline (2007) and project (2022) *carbon stock* accounts for all carbon estimation areas, under each accounting approach tier (A, B and C). The same outcomes are reported at a higher level (i.e. as the sum of all CEAs) in the physical account columns of **Table 4.29** for *carbon abatement* and **Table 4.30** for *carbon stocks*.

Comparison of *carbon abatement* and *carbon stock* accounts derived through the various approaches (i.e. approaches A, B and C) shows large variation among methodologies. For example, overall abatement and stock estimates were ~30% and ~100% higher, respectively, in the 'detailed approach' (B) and 'detailed approach with setting-specific data' (C), than the nationally-consistent approach (A). Where CEA land types were consistent among approaches, the direction of carbon fluxes remained largely the same among, though magnitude of these fluxes often varied (**Table 4.28**).

There were broad similarities between estimates of change in *carbon stock* (2022 stocks minus 2007 stock) and *carbon abatement* estimates integrated across the entire accounting period (2007 to 2022). In all instances, however, change in *carbon stock* is lower than the *carbon abatement* estimate, which is to be expected given the volume of avoided emissions which are incorporated in the latter, but not the former.

Trends in financial accounts among the three different approaches for carbon abatement follow those of the physical accounts (**Table 4.29**), as simple financial multipliers were applied in each circumstance.

Table 4.21: Project-level BlueCAM input parameters, their descriptions and rationale for use in Tomago restoration project carbon abatement accounting. Further guidance on each BlueCAM parameter is provided in ACCU technical documentation.

Project Information Parameter	Input Description / Rationale		Source / Links
	(A) Nationally-consistent approach	(B & C) Detailed approach	
Climatic zone	Climate: BlueCAM uses climatic regions aligned with the Australian Government's Natural Resource Management (NRM) regions approach for projecting the influence of climate change to estimate regionally specific abatement. The Hunter River estuary is positioned within the East Coast cluster, and is therefore considered 'subtropical' in the application of BlueCAM.		NRM regions
Reporting period start date (day/month/year)	Baseline (pre-restoration) date assumed to be 1st of January, 2007		
Reporting period end date (day/month/year)	Project (post-restoration) reporting period assumed to be 31st of December, 2022		
Project permanence period	As defined in the Guide, EEA projects can select a project accounting period of either 25 years or 100 years. Projects with a permanence period of 25 years (and projects with a 100 year permanence period which are subject to the project area discount) are subject to a 25% reduction in carbon abatement estimates, which is applied automatically by BlueCAM. A project accounting period of 100 years, with no project area discount has been selected for the Tomago EEA as this EEA case study is concerned with a short-term (2007-2022) accounting period, and therefore should not be subject to estimate reductions associated with longer-term ACCU projects.		
Apply project area discount?	Input = 'No' A project accounting period of 100 years, with no project area discount has been selected for the Tomago EEA as this EEA case study is concerned with a short-term (2007-2022) accounting period, and therefore should not be subject to estimate reductions associated with longer-term ACCU projects.		
Enter the tidal range (m)	The distribution of coastal wetland types, their carbon cycling parameters, and responses to anticipated sea-level rise are influenced by tidal inundation parameters. Tidal range data for the nearest public tidal gauge at Hexham Bridge. LAT = -0.71 m AHD HAT = 1.14 m AHD Input value = 1.85 m	Site-specific tidal range data for the Tomago restoration site have been sourced from WRL water level loggers co-located with tidal restoration Swing Gates. Estimates supplied by UNSW Water Research Laboratory LAT = -0.50 m AHD HAT = 0.45 m AHD Input value = 0.95 m	Hexham Bridge tidal gauge
Fuel consumed during reporting period	A general principle in many carbon accounting frameworks is that carbon pools or emissions which represent less than 5% of overall project abatement may be considered 'de minimis'. For the purpose of EEA reporting, fuel consumption may be assumed to be zero for project activities (where it is reasonable to assume these emissions represent). Fuel consumption is assumed 'de minimis' for project activities associated with the Tomago restoration site and therefore accounted as zero in BlueCAM.		
Carry over net abatement from the previous reporting period	There were no previous reporting periods (i.e. a single reporting period was used for EEA estimation purposes), therefore no value is entered here.		

Table 4.22: Carbon Estimation Area (CEA) BlueCAM input parameters, their descriptions and rationale for use in Tomago restoration project carbon abatement accounting. *See also **Table 4.26** for BlueCAM replacement parameters with site- and setting-specific values for a more refined, detailed approach (C). *Continued over page.*

CEA Parameter	Input Description / Rationale		Source / Links
	Nationally-consistent approach (A)	Detailed approach (B)*	
CEA area (ha)	Area of each unique change (pre-restoration to post-restoration) class, as determined from national extent mapping approach Input values in **Table 4.24**	Area of each unique change (pre-restoration to post-restoration) class, as determined from detailed extent mapping approach Input values in **Table 4.24**	**Extent account** **Table 4.24**
Elevation of CEA (m AHD)	Median elevation value of all cells within CEA, as derived from nationally-available, high resolution DEM Input values in **Table 4.24**	Median elevation value of all cells within CEA, as derived from nationally-available, high resolution DEM Input values in **Table 4.24**	**Detailed approach** **Table 4.24**
Tidal introduction in CEA?	Input = 'Yes' for all CEAs as they are within the limits of the restoration extent mapping and all CEA median elevation estimates are within the range of national approach LAT to HAT values in **Table 4.21**.	Input = 'Yes' for CEAs (Table X.Z) within the limits of the restoration extent mapping and with CEA median elevation estimates within the range of detailed approach LAT to HAT values in **Table 4.21**: i.e. all CEAs except D5 and D9 Input = 'No' for CEAs D5 and D9 (**Table 4.24**) which have CEA median elevation estimates outside the range of detailed approach LAT to HAT values in **Table 4.21**.	Restoration extent maps (**Figure 1.1**); Detailed DEM (**Detailed approach**) Tidal range and tidal plane (LAT, HAT) estimates (**Table 4.21**); CEA median elevation estimates (**Table 4.24**)
New CEA or first reporting period?	Input = 'Yes' for CEAs which experience a change in land type: N3-N5; N7-N15 Input = 'No' for following CEAs as they remained the same land type: N1, N2, N6, N16	Input = 'Yes' for CEAs which experience a change in land type: D2-D12 Input = 'No' for CEAs which remained the same land type: D1	**Table 4.24** **Table 4.24**
CEA baseline land type	Derived from pre-restoration national extent account approach. Extent account land type harmonized approach with BlueCAM-specific land types as per **Table 4.21** Input values in **Table 4.24**	Derived from pre-restoration detailed extent account approach. Extent account land type harmonized approach with BlueCAM-specific land types as per **Table 4.23** Input values in **Table 4.24**	**Extent account** **Table 4.23** **Table 4.24**
Land type for CEA: last reporting period end	N/A (only one reporting period used)		
Land type for CEA: current reporting period end	Derived from pre-restoration national extent account approach. Extent account land type harmonized approach with BlueCAM-specific land types as per **Table 4.23** Input values in **Table 4.24**	Derived from pre-restoration detailed extent account approach. Extent account land type harmonized approach with BlueCAM-specific land types as per **Table 4.23** Input values in **Table 4.24**	**Table 4.23** **Table 4.24**
Age of blue carbon vegetation in previous reporting period (years)	Age of vegetation at baseline (2007). Input = 20 years for all CEAs. Assumed value to be representative of carbon stocks of mature vegetation		**Table 4.24**

Table 4.22: Cont.

CEA Parameter	Input Description / Rationale		Source / Links
	Nationally-consistent approach (A)	Detailed approach (B)*	
Age of blue carbon vegetation in current reporting period (years)	Age of vegetation at reporting period (2022). Input = 16 years (age assumed; post restoration timeframe) for CEAs which experienced a change in land type: N3-N5; N7-N15 Input = 36 years for blue carbon vegetation CEAs which remained same land type (age assumed; 20 year assumed baseline age + 16 year post restoration timeframe): N1, N2, N6, N16		Table 4.24
Excavation area within CEA (hectares)	Assumed zero		

Table 4.23: Harmonisation of land type extent classes and BlueCAM prescribed land type input classes for Hunter case study.

	Extent account land type	BlueCAM land type
Nationally-consistent approach		
Pre-restoration extent classes	Mangrove	Mangrove
	Saltmarsh	Saltmarsh
	Supratidal forests	Supratidal forest
	Other land covers	Other use land
Post-restoration extent classes	Mangrove	Mangrove
	Saltmarsh	Saltmarsh
	Supratidal forests	Supratidal forest
	Waterbodies/Mudflats	Saline waterbodies
	Other land covers	Other use land
Detailed approach		
Pre-restoration extent classes	Supratidal forest	Supratidal forest
	Grass, pasture	Grazing land
	Dry scrub or cleared land	Grazing land
Post-restoration extent classes	Supratidal forest	Supratidal forest
	Saltmarsh	Saltmarsh
	Grass	Other use land
	Intertidal mudflats and ponds	Other coastal wetland ecosystem

Table 4.24: BlueCAM input values for specific Carbon Estimation Areas (CEAs) derived from classification of land type changes as determined from nationally-consistent and detailed ecosystem extent approaches. Note: Median elevation estimate was used in preference over mean elevation, with the latter included here for reference only.

CEA ID	CEA baseline land type	Land type for CEA: current reporting period end	CEA Area (ha)	CEA elevation (m AHD): median of all cells	CEA elevation (m AHD): mean of all cells
(A) Nationally-consistent approach					
N1	Mangrove	Mangrove	4.0	0.36	0.25
N2	Saltmarsh	Saltmarsh	83.7	0.43	0.41
N3	Saltmarsh	Saline waterbodies	18.5	0.30	0.28
N4	Saltmarsh	Other use land	0.4	0.32	0.29
N5	Supratidal forest	Saltmarsh	6.7	0.34	0.32
N6	Supratidal forest	Supratidal forest	19.3	0.44	0.42
N7	Supratidal forest	Saline waterbodies	1.0	0.30	0.29
N8	Supratidal forest	Other use land	6.2	0.39	0.38
N9	Other use land	Saltmarsh	47.6	0.35	0.33
N10	Other use land	Supratidal forest	24.3	0.48	0.46
N11	Other use land	Saline waterbodies	25.7	0.26	0.26
N12	Other use land	Other use land	61.7	0.46	0.44
(B & C) Detailed approach					
D1	Supratidal forest	Supratidal forest	20.7	0.40	0.41
D2	Supratidal forest	Saltmarsh	7.9	0.35	0.36
D3	Supratidal forest	Other use land	0.1	0.44	0.43
D4	Supratidal forest	Other coastal wetland ecosystem	1.1	0.28	0.29
D5 **	Grazing land	Other use land	2.7	0.61	0.64
D6	Grazing land	Other coastal wetland ecosystem	23.6	0.32	0.33
D7	Grazing land	Saltmarsh	52.8	0.43	0.45
D8	Grazing land	Supratidal forest	31.4	0.45	0.47
D9 **	Grazing land *	Other use land *	0.5	0.60	0.61
D10	Grazing land *	Other coastal wetland ecosystem *	38.3	0.28	0.29
D11	Grazing land *	Saltmarsh *	80.1	0.39	0.40
D12	Grazing land *	Supratidal forest *	34.4	0.42	0.42

* apparent duplication of land type conversion classes is due to differences in the original land type classes from the extent account output. As these 'duplicates' may have different elevation values, they have been retained as separate CEAs

** these CEAs have median and mean elevation values outside the range of the Highest Astronomical Tide and are therefore considered to have not experienced tidal restoration

Table 4.25: Context and source of published and unpublished carbon parameter estimates used in place of **BlueCAM parameters in the detailed approach (C).** Source letters are footnotes for values supplied in **Table 4.26**.

Parameter	BlueCAM column #	Data context	Replacement value and units	Source	Ref
Baseline avoided emissions of CH_4 (EB,CH_4) (tonnes CO_2e)	W*	Site-specific estimate of pre-restoration CH_4 emissions from Stage 3 area of Tomago restoration project. Applied to CEAs with herbaceous vegetation in baseline scenario (i.e. 'grazing land')	- 0.22 $tCO_2e\ ha^{-1} yr^{-1}$	*a*	199
Coastal wetland emissions ($E_{CW,CH4}$) (tonnes CO_2e)	Z*	Site-specific estimate of post-restoration saltmarsh CH_4 emissions from Stage 3 area of Tomago restoration project. Applied to CEAs with saltmarsh vegetation in project scenario	- 0.56 $tCO_2e\ ha^{-1} yr^{-1}$	*a*	199
ETR emissions from baseline vegetation (40% AGB for 1 year) (t $CO_2e\ ha^{-1}$)	BB	Setting-specific estimate of aboveground biomass of Swamp Oak Floodplain Forests from multiple sites in subtropical and temperate Australia. This is the specific vegetation community type which dominates the supratidal forests of the Tomago site. Applied to CEAs with supratidal forest in the baseline scenario	209.9 $tCO_2e\ ha^{-1}$	*b*	200
AGB (t $CO_2e\ ha^{-1}$)	BI	Setting-specific dataset. BlueCAM value multiplied by a value of 1.43 (the ratio of setting-specific value : BlueCAM value in row BB)	82.5 to 111.2 $tCO_2e\ ha^{-1}$	*b*	200
BGB (t $CO_2e\ ha^{-1}$)	BJ		26.4 to 35.6 $tCO_2e\ ha^{-1}$	*b*	200
Soil C accumulation (t $CO_2e\ ha^{-1}$)	BK	Setting-specific dataset. Mean of multiple surface soil carbon accumulation estimates derived from Swamp Oak Floodplain Forests from multiple sites in subtropical and temperate Australia. Applied to CEAs with supratidal forest in the project scenario	3.6 $tCO_2e\ ha^{-1} yr^{-1}$	*b*	201
		Setting-specific dataset. Mean of multiple surface soil carbon accumulation estimates derived from cores collected in tidal restoration sites (Kooragang Island, Hexham Swamp) and an undisturbed reference site (Kooragang Island) within the Hunter estuary. Applied to CEAs with saltmarsh in the project scenario	2.4 $tCO_2e\ ha^{-1} yr^{-1}$	*b*	201
Soil C stock (t $CO_2e\ ha^{-1}$)	BL	Setting-specific estimate of soil carbon stocks (to 1m depth) of Swamp Oak Floodplain Forests from multiple sites in subtropical and temperate Australia. This is the specific vegetation community type which dominates the supratidal forests of the Tomago site. Applied to CEAs with supratidal forest in baseline scenario	888.4 $tCO_2e\ ha^{-1}$	*b*	200
		Site-specific dataset. Soil carbon stocks (to 1m depth) collected across multiple settings of herbaceous vegetation in the Tomago Stage 3 restoration area. Cores were collected within 18 months of Stage 3 tidal restoration, and are are assumed to be representative of baseline soil carbon stocks. Applied to CEAs with herbaceous vegetation in baseline scenario (i.e. 'grazing land')	878.2 $tCO_2e\ ha^{-1}$	*d*	202

[199] Negandhi, K., et al. "Blue carbon potential of coastal wetland restoration varies with inundation and rainfall." Scientific Reports, 9 (2019), 4368. https://doi.org/10.1038/s41598-019-40763-8.

[200] Kelleway, J. J., et al. "Carbon Storage in the Coastal Swamp Oak Forest Wetlands of Australia." In Wetland Carbon and Environmental Management (eds K.W. Krauss, Z. Zhu, and C.L. Stagg). https://doi.org/10.1002/9781119639305.ch18.

[201] Lovelock, C. E., et al. "Modeled approaches to estimating blue carbon accumulation with mangrove restoration to support a blue carbon accounting method for Australia." Limnology and Oceanography, 67 (2022), S50-S60. https://doi.org/10.1002/lno.12014.

[202] Kelleway, J. J. "Soil carbon stock estimates for Tomago tidal restoration site." (Unpublished Data).

Table 4.26: Details of setting-specific published and unpublished estimates which have been used to replace input and/or calculation parameters of the BlueCAM calculator. Replacement values have been determined on the basis of each CEA, and include datasets collect within the Hunter estuary and/or nearby locations. Source letters refer to entries in **Table 4.25**. *Continued over page.*

		BlueCAM parameters											
CEA ID		Baseline avoided emissions of CO_2 ($E_{B,CO2}$) (tonnes CO_2)	Baseline avoided emissions of CH_4 ($E_{B,CH4}$) (tonnes CO_2e)	Baseline avoided emissions of N_2O ($E_{B,N2O}$) (tonnes CO_2e)	Coastal wetland emissions ($E_{CW,CO2}$) (tonnes CO_2e)	Coastal wetland emissions ($E_{CW,CH4}$) (tonnes CO_2e)	Coastal wetland emissions ($E_{CW,N2O}$) (tonnes CO_2e)	ETR emissions from baseline vegetation (40% AGB for 1 year) (t CO_2e ha^{-1})	ETR emissions from blue C wetlands (40% AGB for 1 year) (t CO_2e ha^{-1})	AGB (t CO_2e ha^{-1})	BGB (t CO_2e ha^{-1})	Soil C accumulation (t CO_2e ha^{-1})	Soil C stock (t CO_2e ha^{-1})
	BlueCAM row/cell:	V	W	X	Y	Z	AA	BB	BC	BI	BJ	BK	BL
D1	BlueCAM value	0	39.75	16.56	0	39.75	16.56	0.0	0.0	77.7	24.9	35.9	403.3
	Replacement value									**111.2**	**35.6**	**38.4**	**884.5**
	Source									*b*	*b*	*c*	*b*
D2	BlueCAM value	0	15.25	6.35	0	20.33	91.50	146.7	0.0	5.0	0.0	28.2	403.3
	Replacement value					**-27.96**		**209.9**				**57.0**	**884.5**
	Source					*a*		*b*				*c*	*b*
D3	BlueCAM value	0	0.12	0.05	0	0	0	146.7	0.0	0.0	0.0	0.0	403.3
	Replacement value							**209.9**					**884.5**
	Source							*b*					*b*
D4	BlueCAM value	0	2.03	0.85	0	0	0	146.7	0.0	0.0	0.0	0.0	403.3
	Replacement value							**209.9**					**884.5**
	Source							*b*					*b*
D5	BlueCAM value	0	0	0	0	0	0	7.7	0.0	0.0	0.0	0.0	239.4
	Replacement value		**-24.50**										**878.2**
	Source		*a*										*d*

Table 4.26: Cont.

CEA ID		BlueCAM parameters											
		Baseline avoided emissions of CO_2 ($E_{B,CO2}$) (tonnes CO_2)	Baseline avoided emissions of CH_4 ($E_{B,CH4}$) (tonnes CO_2e)	Baseline avoided emissions of N_2O ($E_{B,N2O}$) (tonnes CO_2e)	Coastal wetland emissions ($E_{CW,CO2}$) (tonnes CO_2e)	Coastal wetland emissions ($E_{CW,CH4}$) (tonnes CO_2e)	Coastal wetland emissions ($E_{CW,N2O}$) (tonnes CO_2e)	ETR emissions from baseline vegetation (40% AGB for 1 year) (t CO_2e ha^{-1})	ETR emissions from blue C wetlands (40% AGB for 1 year) (t CO_2e ha^{-1})	AGB (t CO_2e ha^{-1})	BGB (t CO_2e ha^{-1})	Soil C accumulation (t CO_2e ha^{-1})	Soil C stock (t CO_2e ha^{-1})
	BlueCAM row/cell:	V	W	X	Y	Z	AA	BB	BC	BI	BJ	BK	BL
D6	BlueCAM value	0	0	33.98	0	0	0	7.7	0.0	0.0	0.0	0.0	239.4
	Replacement value		**-211.43**										**878.2**
	Source		*a*										*d*
D7	BlueCAM value	0	0	76.08	0	168.98	760.42	7.7	0.0	5.0	0.0	28.2	239.4
	Replacement value		**-473.39**			**-185.97**						**57.0**	**878.2**
	Source		*a*			*a*						*c*	*d*
D8	BlueCAM value	0	0	45.21	0	75.32	31.38	7.7	0.0	57.7	18.4	35.9	239.4
	Replacement value		**-281.34**							**82.5**	**26.4**	**38.4**	**878.2**
	Source		*a*							*b*	*b*	*c*	*d*
D9	BlueCAM value	0	0	0	0	0	0	7.7	0.0	0.0	0.0	0.0	239.4
	Replacement value		**-4.46**										**878.2**
	Source		*a*										*d*
D10	BlueCAM value	0	0	55.15	0	0	0	7.7	0.0	0.0	0.0	0.0	239.4
	Replacement value		**-343.19**										**878.2**
	Source		*a*										*d*
D11	BlueCAM value	0	0	115.35	0	205.06	922.79	7.7	0.0	5.0	0.0	28.2	239.4
	Replacement value		**-717.72**			**-282.0**						**57.0**	**878.2**
	Source		*a*			*a*						*c*	*d*
D12	BlueCAM value	0	0	49.49	0	65.99	27.49	7.7	0.0	57.7	18.4	35.9	239.4
	Replacement value		**-307.93**							**82.5**	**26.4**	**38.4**	**878.2**
	Source		*a*							*b*	*b*	*c*	*d*

Table 4.27: Summary of carbon stock accounting approach, including instruction for application of equations to BlueCAM calculator files in Excel.

Stock account	BlueCAM input file(s) used	Equation applied to BlueCAM file for each CEA*
Aboveground biomass carbon stock (2007) [$AGB_{baseline}$]	BlueCAM file used for carbon abatement account	$AGB_{baseline} = BBx*2.5*Kx$
Soil carbon stock to 1m (2007) [$Soil_{baseline}$]	BlueCAM file used for carbon abatement account	$Soil_{baseline} = BLx*Kx$
Aboveground biomass carbon stock (2022) [$AGB_{project}$]	New (additional) BlueCAM file with all 'New CEA or first reporting period?' inputs entered as 'Yes' Note: $AGB_{baseline}$ parameter derived as per carbon abatement file above	$AGB_{project} = AGB_{baseline} + BIx*Kx-ABx$
Soil carbon stock to 1m (2022) [$Soil_{project}$]	Same BlueCAM file as used for carbon abatement account Note: $Soil_{baseline}$ parameter derived as per carbon abatement file above	$Soil_{project} = Soil_{baseline} + AMx$

* where italicised letters (e.g. K, AB, BB) refer to BlueCAM Excel columns and 'x' refers to the Excel row number for a given CEA)

Table 4.28: BlueCAM output values for each Carbon Estimation Areas (CEAs) over the period 2007-2022, derived from classification of land type changes as determined from nationally-consistent and detailed approaches for the Tomago restoration case study. *Continued over page.*

			Carbon abatement			Carbon stocks			
CEA ID	CEA baseline land type	Land type for CEA: current reporting period end	CEA total emissions avoided ($E_{A,i}$) (tonnes CO_2e)	CEA total carbon sequestered in vegetation ($C_{v,i}$) (tonnes CO_2e)	CEA total carbon sequestered in soil (tonnes CO_2e)	Vegetation biomass carbon stocks - baseline AGB tCO_2e	Vegetation biomass carbon stocks - project AGB tCO_2e	Soil carbon stocks - baseline tCO_2e	Soil carbon stocks - project tCO_2e
	(A) Nationally-consistent approach								
N1	Mangrove	Mangrove	-65	307	110	1,465	1,776	4,516	4,626
N2	Saltmarsh	Saltmarsh	0	418	2,358	1,044	1,462	41,432	43,790
N3	Saltmarsh	Saline waterbodies	168	0	0	230	138	9,133	9,133
N4	Saltmarsh	Other use land	3	0	0	4	3	178	178
N5	Supratidal forest	Saltmarsh	-1,053	33	152	2,442	1,498	2,686	2,838
N6	Supratidal forest	Supratidal forest	-13	1,976	691	7,062	8,559	7,768	8,459
N7	Supratidal forest	Saline waterbodies	-143	0	-36	363	218	399	363
N8	Supratidal forest	Other use land	-894	0	-36	2,277	1,366	2,505	2,469
N9	Other use land	Saltmarsh	-838	238	1,341	0	238	5,471	6,812
N10	Other use land	Supratidal forest	-83	1,849	871	0	1,401	2,792	3,664
N11	Other use land	Saline waterbodies	0	0	0	0	0	2,947	2,947
N12	Other use land	Other use land	0	0	0	0	0	7,084	7,084
	TOTAL		**-2,916**	**4,821**	**5,452**	**14,888**	**16,658**	**86,911**	**92,363**
	(B) Detailed approach								
D1	Supratidal forest	Supratidal forest	0	2,123	742	7,587	9,195	8,345	9,087
D2	Supratidal forest	Saltmarsh	-1,255	40	188	2,911	1,786	3,202	3,390
D3	Supratidal forest	Other use land	-9	0	-36	24	14	26	-10
D4	Supratidal forest	Other coastal wetland ecosystem	-152	0	-36	388	233	427	391
D5	Grazing land	Other use land	-21	0	0	53	32	654	654
D6	Grazing land	Other coastal wetland ecosystem	-148	0	6	454	272	5,647	5,653
D7	Grazing land	Saltmarsh	-1,260	264	1,494	1,017	873	12,643	14,137
D8	Grazing land	Supratidal forest	-303	2,388	1,131	604	2,172	7,514	8,645

Table 4.28: Cont.

			Carbon abatement			Carbon stocks			
CEA ID	CEA baseline land type	Land type for CEA: current reporting period end	CEA total emissions avoided ($E_{A,i}$) (tonnes CO_2e)	CEA total carbon sequestered in vegetation ($C_{v,i}$) (tonnes CO_2e)	CEA total carbon sequestered in soil (tonnes CO_2e)	Vegetation biomass carbon stocks - baseline AGB tCO_2e	Vegetation biomass carbon stocks - project AGB tCO_2e	Soil carbon stocks - baseline tCO_2e	Soil carbon stocks - project tCO_2e
D9	Grazing land	Other use land	-4	0	0	10	6	119	119
D10	Grazing land	Other coastal wetland ecosystem	-240	0	6	737	442	9,166	9,172
D11	Grazing land	Saltmarsh	-1,629	400	2,261	1,541	1,324	19,169	21,431
D12	Grazing land	Supratidal forest	-308	2,614	1,237	661	2,377	8,224	9,462
	TOTAL		**-5,329**	**7,828**	**6,993**	**15,986**	**18,727**	**75,137**	**82,131**
	(C) Detailed approach with setting-specific carbon data								
D1	Supratidal forest	Supratidal forest	0	3,037	794	10,859	13,160	18,300	19,095
D2	Supratidal forest	Saltmarsh	-1,708	40	417	4,166	2,539	7,021	7,438
D3	Supratidal forest	Other use land	-13	0	-36	34	20	57	21
D4	Supratidal forest	Other coastal wetland ecosystem	-219	0	-36	556	333	936	900
D5	Grazing land	Other use land	-46	0	0	53	32	2,400	2,400
D6	Grazing land	Other coastal wetland ecosystem	-359	0	6	454	272	20,712	20,718
D7	Grazing land	Saltmarsh	-1,378	264	3,018	1,017	873	46,374	49,392
D8	Grazing land	Supratidal forest	-584	3,418	1,211	604	2,952	27,560	28,771
D9	Grazing land	Other use land	-8	0	0	10	6	437	437
D10	Grazing land	Other coastal wetland ecosystem	-583	0	6	737	442	33,619	33,624
D11	Grazing land	Saltmarsh	-1,860	400	4,573	1,541	1,324	70,309	74,882
D12	Grazing land	Supratidal forest	-616	3,741	1,325	661	3,231	30,165	31,490
	TOTAL		**-7,376**	**10,899**	**11,278**	**20,690**	**25,185**	**257,890**	**269,167**

Table 4.29: Physical accounts and financial accounts of Avoided Emissions and Carbon Sequestration outcomes of the Tomago tidal restoration project over the period 2007-2022, as estimated from three contrasting approaches: (A) a low-resolution but nationally-consistent approach; (B) a detailed approach using high-resolution mapping products and tidal range data; and (C) a detailed approach using high-resolution mapping products and tidal range data, as well as setting-specific carbon parameters as detailed in Table 4.25 and Table 4.26.

		(A) Nationally-consistent approach			(B) Detailed approach			(C) Detailed approach with setting-specific carbon data		
		Physical account (Tonnes CO_2e)	Financial account (AUD) - ACCU SPOT	Financial account (AUD) - Premium	Physical account (Tonnes CO_2e)	Financial account (AUD) - ACCU SPOT	Financial account (AUD) - Premium	Physical account (Tonnes CO_2e)	Financial account (AUD) - ACCU SPOT	Financial account (AUD) - Premium
BlueCAM outputs	Reporting period emissions avoided (E_A)	-2,916	-$89,671	-$437,417	-5,329	-$163,861	-$799,324	-7,376	-$226,802	-$1,106,351
	Reporting period C sequestered in vegetation and soil (CP)	10,273	$315,895	$1,540,952	14,821	$455,742	$2,223,131	22,176	$681,914	$3,326,409
	Emissions from fuel consumed during reporting period (E_{fk})	0	$0	$0	0	$0	$0	0	$0	$0
	Net abatement amount (A_r): BlueCAM calculator output	6,843	$210,430	$1,026,487	8,751	$269,093	$1,312,650	13,692	$421,016	$2,053,738
Net abatement amount ($A_{r\text{-}adj}$): ACCU discount removed		7,357	$226,225	$1,103,535	9,492	$291,880	$1,423,807	14,800	$455,112	$2,220,058

Table 4.30: Physical accounts only of baseline and end of accounting period carbon stocks in Tomago restoration site vegetation and soil pools over the period 2007-2022, as estimated from three contrasting approaches: (A) a low-resolution but nationally-consistent approach; (B) a detailed approach using high-resolution mapping products and tidal range data; and (C) a detailed approach using high-resolution mapping products and tidal range data, as well as setting-specific carbon parameters as detailed in Table 4.25 and Table 4.26.

		(A) Nationally-consistent approach	(B) Detailed approach	(C) Detailed approach with setting-specific carbon data
		Physical account (Tonnes CO_2e)	Physical account (Tonnes CO_2e)	Physical account (Tonnes CO_2e)
BlueCAM outputs	Vegetation aboveground biomass carbon stocks - baseline	14,888	15,986	20,690
	Vegetation aboveground biomass carbon stocks - project	16,658	18,727	25,185
	Soil carbon stocks - baseline	86,911	75,137	257,890
	Soil carbon stocks - project	92,363	82,131	269,167
	Total carbon stocks - baseline	101,800	91,123	278,580
	Total carbon stocks - project	109,022	100,857	294,352
	Net carbon stock change (project - baseline)	7,222	9,734	15,772

Interpretation and discussion

Carbon abatement (Physical and Financial accounts):

Depending on the accounting approach taken, estimates of *carbon abatement* volume across the 16 years since tidal restoration at Tomago range from 7,357 to 14,800 t CO_2e. This volume of *abatement* equates to the annual electricity emissions of approximately 1,431 to 2,880 households, or 122,000– 245,000 tree seedlings grown for 10 years (US EPA[203]).

Inspection of accounts at the level of individual CEAs (Table 4.28) demonstrates a high degree of variation in the carbon abatement among different areas of the Tomago restoration project. For example, where areas of supratidal forests remained as supratidal forests following tidal restoration (i.e. CEAs N6 and D1 in the national and detailed approaches, respectively), carbon abatement outcomes were overwhelmingly positive (i.e. a net CO_2 sink). In contrast, areas of supratidal forest which converted to other land covers (e.g. CEAs N5, N7, N8, D2-4) typically returned negative abatement outcomes (i.e. a net source of CO_2 to the atmosphere). This negative abatement is associated largely with CO_2 emissions from vegetation transition (dieback of carbon-rich trees; E_A), but also reduced rates of sequestration in the new vegetation type (Cv) and/or their associated soils, compared to the previous forest. The largest CEAs by area (i.e. areas where saltmarsh or supratidal forest persisted or where new saltmarsh or supratidal forest generated on former grazing land) were net CO_2e sinks, leading to sizeable and positive overall abatement outcomes for the Tomago restoration project.

One of the most significant outcomes of this case study was the extent to which *carbon abatement* accounts varied among methodologies (i.e. up

[203] United States Environmental Protection Agency. "Greenhouse Gas Equivalencies Calculator." https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator. (Accessed March 29, 2023).

to 2-fold differences among approaches A and C). Some of this variation appears associated with the capacity for a detailed extent account to more accurately define pre-restoration land types compared to the nationally-consistent approach which mapped areas of mangrove and large expanses of saltmarsh in areas devoid of tidal exchange in the pre-restoration scenario. This mapping which was a crucial first step in defining CEAs used in the carbon accounts and largely defined to carbon abatement estimates for each CEA. Comparison of the two detailed approaches (B and C) – which utilised the same mapping products and therefore had common CEAs – highlights the significance of utilizing setting-specific carbon parameters in the Tomago case study. That is, overall abatement estimates were more than 50 % higher (or 5,308 t CO_2e higher) under approach C, which outranks the differences due to mapping resolutions between approaches A and B.

While site- or setting-specific values were available for some land types and some carbon parameters, most instances still required use of generic BlueCAM values (**Table 4.26**). The collection of new site- and setting-specific data to populate missing parameters (or update existing literature values) may lead to further refinement of the tier C detailed accounts, though the direction and magnitude of these changes cannot currently be known.

Overall, we conclude that the substantially higher carbon abatement estimates derived using setting-specific data highlight the conservative nature of the generic BlueCAM approach in this carbon-rich and data-rich setting. On this basis, we recommend, that where setting-specific data is available or can be collected through the life of a restoration project, then undertaking a type C approach is advisable. Such data collection may also be useful to future refinements of carbon accounting mechanisms, including BlueCAM.

Carbon stocks (physical account only):

The carbon stock accounts demonstrate the substantial amount of carbon stored within the coastal wetlands of the Tomago site. Stock estimates were high (>90,000 t CO_2e) in both baseline (2007) and project (2022) accounts under all approaches, and as high as 294,352 t CO_2e in the highest case project scenario (**Table 4.30**). These stock estimates equate to the to the annual electricity emissions of approximately 17,700 to 57,300 households, or the amount of carbon sequestered by growing 1.5 to 4.9 million tree seedlings for 10 years (US EPA, 2023[204]). This finding demonstrates the carbon-rich nature of the Tomago setting, and the significant amount of carbon which may be at risk of emission to the atmosphere if the site is disturbed or restoration practices are reversed.

Under all approaches, carbon stocks within the surface 1m of soils exceeded estimates of carbon stock with the aboveground biomass pool (**Table 4.30**). Interestingly, this disparity was greatest in the detailed approach incorporating setting-specific data, which highlights the conservative nature of the generic BlueCAM approach for estimating soil carbon stocks in settings (such as Tomago) where local data reveal large carbon stocks.

The estimated change in total carbon stocks is similar to estimates of overall abatement completed at the same detail level in this case study (e.g. stock change of 7,222 tonnes CO_2e for the national approach, compared to a national approach abatement estimate 7,357 tonnes CO_2e). We caution, however, against the use of a simple stock change approach as a measure of carbon abatement outcome. This is because a stock change approach (incorporating only aboveground biomass and soil carbon to 1m) does not consider avoided emissions, all carbon pools (e.g. belowground biomass) or fluxes (e.g. methane and nitrous oxide emissions), the latter of has particular potential to greatly alter abatement outcomes in some baseline and/or project settings.

We also re-iterate that no financial account was estimated for *carbon stocks* (or change in carbon stock), as doing so would lead to double-counting of financial accounts which are already incorporated in the *carbon abatement* account.

Both *carbon abatement* and *carbon stock* accounts were constrained by significant limitations. First, these carbon accounts were informed by national and detailed extent accounts and are therefore subject to the same limitations and uncertainties inherent in those approaches,

[204] United States Environmental Protection Agency. "Greenhouse Gas Equivalencies Calculator." https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator. (Accessed March 29, 2023).

detailed in earlier sections. Second, the availability of site-specific tidal range parameters utilised in approaches B and C (site-specific tidal range estimate of 0.95m) highlighted the less suitable nature of nationally-available datasets (i.e. public tide gauge data with tidal range estimate of 1.85m) for carbon accounting purposes. While this did not appear to have a significant impact on carbon accounts in the current case study at Tomago, this may be an important factor to consider in other projects. Finally, the increase in overall carbon abatement and carbon stock accounts when using the most detailed approach highlights the significance of applying. While the Tomago case study had access to setting-specific parameters for some land types and some specific carbon cycling parameters, there remain significant data gaps for the majority of data inputs which prevented more accurate determination of the true abatement and stock outcomes of the Tomago restoration project.

4.4.2 Flood control services

Intent and approach

The aim of this section was to assess the capacity of Tomago wetlands to reduce the assets at risk of flood damage. Flood protection services are associated with extreme events, which do not occur frequently and may not be relevant to all coastal wetlands. The recommended approach was to use available information in a three-step process to rapidly assess whether the mitigation services are relevant onsite. This three-step process included assessing:

1. Whether flood processes occur within the catchment Tomago wetland
2. Whether there are assets (e.g. properties or infrastructure) at risk as a result of flooding
3. Whether there are mechanisms for the restored wetland to have altered flood pathways or processes within the catchment

If this three-step process indicates that flood mitigation services are relevant, process-based flood modelling can be used to quantify the number of properties provided with additional flood protection because of the restoration works for the physical accounts. This can then be used to estimate the reduction in flood damages for the monetary accounts. This assessment accounts for the small change in assets at risk of flooding because of the restoration works. The flood mitigation protection provided by built infrastructure that pre-date on-ground works cannot be directly linked to the restoration and is therefore not considered to be a service provided by the restoration activity.

Results

Riverine flood processes occur in the lower Hunter River, where Tomago wetlands are located. Flooding in the Hunter River estuary is well documented and has been the subject of numerous studies. There are records of significant historical floods which have caused extensive damage across the floodplain. Most significantly, in response to extreme floods in 1955, the Hunter Valley Flood Mitigation Scheme (HVFMS) was developed. Under the scheme, various flood mitigation infrastructure is operated and maintained throughout the catchment, including the Fullerton Cove levee and two major floodgates connecting the restoration area to Fullerton Cove. The assessment concluded that flood processes do occur with the Hunter River floodplain and there is evidence of assets at risk due to flooding.

The final stage of the three-step process is assessing whether there are mechanisms for the restored wetland to reduce the risk of flood damage within the Hunter River floodplain. This assessment considered:

- The potential for provision of additional flood storage by encouraging floodplain inundation (e.g. overtopping of levees or flow through open channels and culverts) in a location that would otherwise be protected from flooding, reducing the volume of floodwater elsewhere in a catchment. Connectivity of Tomago wetlands to the wider Hunter River during flood events is primarily controlled by the Fullerton Cove levee, an asset that pre-dated restoration works and was not altered because of the restoration. The restoration works are not considered to have change the capacity of the land to provide flood storage under any flood event frequencies.
- The potential for improved conveyance of floodwaters during local catchment events. Local flood conveyance at Tomago wetlands is primarily controlled by infrastructure that is part of the HVFMS (including two floodgates, and one major drain). While the floodgates flaps were

modified as part of the restoration works, the culvert size or conveyance capacity was not increased. It was therefore concluded that improvements in flood conveyance were unlikely as a result of the restoration works.

Based on the above analysis, this assessment concluded that the restoration works at Tomago wetlands were unlikely to provide additional flood mitigation services to the surrounding catchment. This assessment recognises the pre-existing flood services of the HVFMS in and around Tomago wetlands prior to restoration, however no additional flood mitigation services have been provided by the restored site in this case. Therefore, a full quantifiable assessment, which would require further resources, is not recommended. To this aim, the accounts for flood mitigation reflect no additional property protection from the restoration activities.

Reflection relative to the Guide

Wetland restoration will not always provide flood mitigation services (and other coastal protection services). Flood mitigation services provided by restored coastal wetlands have been proposed to be measured in the number of properties with additional flood protection and the associated avoided damage costs. Importantly, to assess 'additional' flood protection, it is necessary to have a pre-existing state with which to compare. As the flood protection is not solely associated with vegetated ecosystems (e.g. saltmarsh, mangroves or supratidal forests), but also the infrastructure that supports it (e.g. levees and floodgates), it is recommended that the pre-restoration configuration (including topography, vegetation and drainage infrastructure) is used as the base for assessing marginal change in flood impacts for site level assessment and accounts. Using these assumptions allows for flood benefits to be attributed to the restoration activities. Application of the initial three step assessment process at Tomago Wetlands for flood mitigation services highlights the importance of assessing marginal change in flood processes. In this example, infrastructure that existed in the pre-restoration site (e.g. floodgates and levee systems) may have already provided flood mitigation services and restoration is unlikely to have any measurable influence on flooding mechanisms.

The following sections provide detailed analysis of these summary results.

Supporting information – Flood mitigation services

The supplementary material provided in this section provides additional background information, detail and discussion on the assessment of flood mitigation services provided by the restoration activities at Tomago wetlands. This section includes three main sections:

- Background information on the Hunter Valley Flood Mitigation Scheme.
- Further detail on the three-stage assessment of the relevance of flood mitigation services to the restoration activities at Tomago wetlands.
- Concluding remarks.

Hunter Valley Flood Mitigation Scheme – background information

The Hunter Valley Flood Mitigation (HVFMS) was developed in response to the 1955 floods. It is necessary to include a short background on the HVFMS and the flood asset infrastructure in and around Tomago wetlands to assist in the understanding of flood processes following the restoration activities. The HVFMS is operated and maintained by the NSW Department of Planning and Environment (DPE), with support from Hunter Local Land Services and is managed under the Water Management Act. The purpose of the scheme is to provide protection to the floodplain during small to moderate flood events, and to route floodwaters away from urban areas in major floods. The scheme includes a wide array of infrastructure, including 185 km of levees, 165 km of drains and 259 floodgates[205].

At Tomago wetlands, a number of assets are managed as part of the HVFMS (shown in **Figure 4.2**), including:

- Two floodgates that were modified during restoration (with two-way tidal flushing capacity), indicated in green in **Figure 4.2**.
- Approximately 4.3 km of levees on the south and east boundaries of the site. This is part of the Fullerton Cove levee, which extends along the foreshore of the cove and Hunter River estuary. The Fullerton Cove levee is designed to overtop in events larger than the 2% AEP flood (designed to overtop to become a flood detention

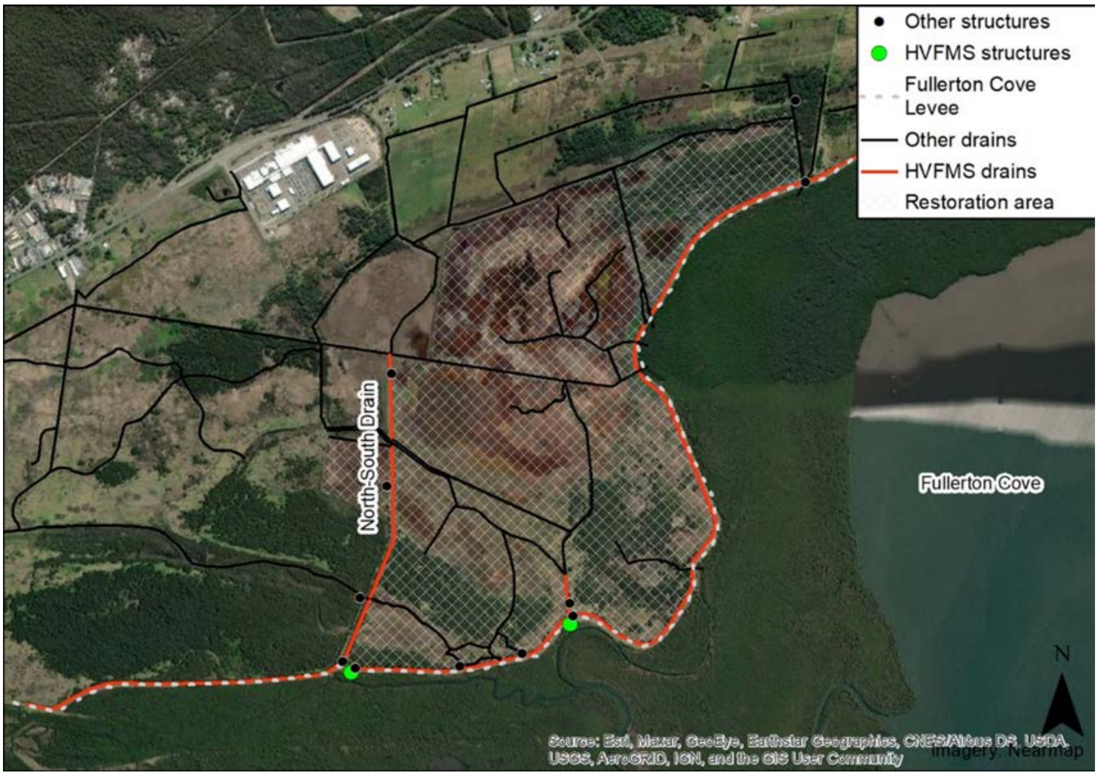

Figure 4.2: HVFM scheme assets adjacent to Tomago Wetlands.

[205] Department of Planning, Industry, and Environment, NSW. "Hunter Valley Flood Mitigation Scheme: Fact Sheet." (2020).

basin), although localised overtopping can occur when water levels in Fullerton Cove reach 1 m AHD (on king high tides).

- Approximately 6 km of drains within the site, including the Fullerton Cove Ring Drain, which runs parallel and upstream of the Fullerton Cove levee, and the North-South Drain which provides drainage to the 200 ha catchment immediately upstream of the Tomago wetlands restoration area.

Three-step assessment of the relevance of flood mitigation services at Tomago wetlands

Within the Guide, it is recognised that flood mitigation services are unlikely to be relevant for all restored coastal wetland systems. The recommended approach includes the application of a three-step assessment using readily available information to assess whether any flood mitigation services are likely to be relevant to a particular site. The following sections outlines the application of the three-step process at Tomago wetlands, including assessing:

1. Whether flood processes occur within the catchment Tomago wetland exists.
2. Whether there are assets (e.g. properties or infrastructure) at risk as a result of flooding.
3. Whether there are mechanisms for the restored wetland to have altered flood pathways or processes within the catchment.

Presence of flood processes

Tomago Wetland covers approximately 300 ha, with typical elevations between 0–0.5 m AHD (**Figure 4.3**). The nearest major waterway is Fullerton Cove, which forms part of the lower Hunter River estuary. Flooding in the Hunter River estuary is well documented and has been subject to numerous flood studies. The two most recent flood studies that cover the Tomago wetlands restoration area are:

- 2005 Williamtown Salt Ash Flood Study[206] – completed just prior to restoration works. This model covered the area of Hunter River floodplain between Raymond Terrace, Fullerton Cove and Salt Ash. It used outputs from another flood model of the lower Hunter River estuary as boundary conditions.
- 2017 Williamtown - Salt Ash Floodplain Risk Management Study & Plan[207] – completed following all restoration activities. Significant updates were included in this model, including linking it in with a model of the Williams River and lower Hunter River (to the entrance at the Pacific Ocean). This allowed for climate change scenarios to be run independently of other flood models. Updates to topography (including floodplain development) were also included in this model.

While typically the most recent flood study should be used for reference in an analysis, both studies have been considered in this case as the 2005 study would have been the most recent at the time of restoration. The design flood water levels on the western side of Fullerton Cove (the tidal waterbody immediately downstream of Tomago wetlands) are provided in **Table 4.31**. Note that there are differences between the two flood studies, including different boundary conditions and the inclusion of new developments, which resulted in changes in flood levels for the 1% AEP and greater events. These changes are not attributable to the restoration works at Tomago Wetlands (which is fully inundated under most flood scenarios).

Figure 4.4 shows the elevation of the Fullerton Cove levee has also been extracted (from the DEM shown in **Figure 4.3**). The elevation of the levee has been shown against the highest astronomical tides (from the closest available long term monitoring gauge at Hexham Bridge[208]) and the 10 % and 2 % AEP levels. Modelled flood heights in Fullerton Cove exceed the floodplain height at Tomago wetlands (>1.2 m AHD for events greater than 50 % AEP)[209], indicating the floodplain has the capacity to interact with floodwaters.

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[206] WBM Oceanics Australia. "Williamtown Salt Ash Flood Study." (2005).
[207] BMT WBM. "Williamtown - Salt Ash Floodplain Risk Management Study & Plan." (2017).
[208] Manly Hydraulics Laboratory. "OEH NSW Tidal Planes Analysis: 1990 - 2010 Harmonic Analysis." (2012).
[209] WBM Oceanics Australia. "Williamtown Salt Ash Flood Study." (2005).

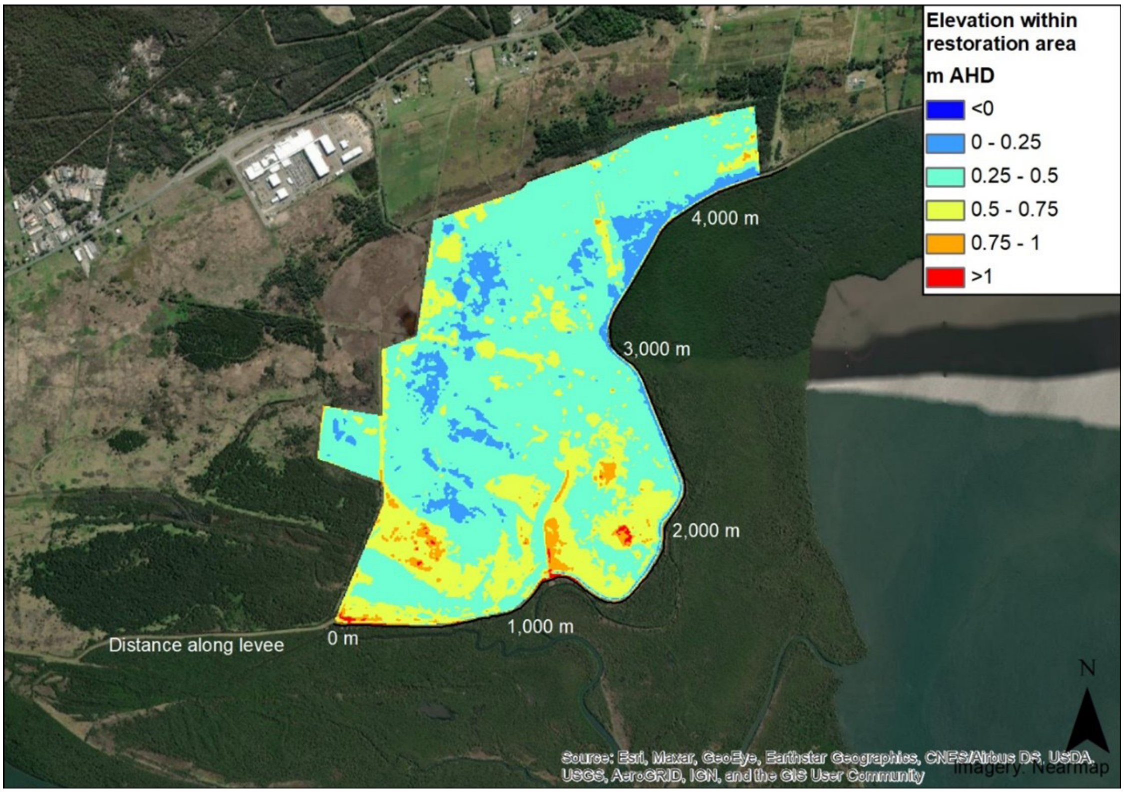

Figure 4.3: Floodplain elevation within the restoration area at Tomago Wetlands (data source: Geoscience Australia, 2015).

Table 4.31: AEP and design flood level in Fullerton Cove (western side).

Average Exceedance Probability (AEP)	Design flood level[210]	Design flood level[211]
50%	1.2	Not reported
20%	1.2	Not reported
10%	1.3	1.3
5%	1.3	1.3
2%	1.4	1.4
1%	2.1	1.8
0.5%	2.6	2.1
PMF (Probable Maximal Flood)	4.7	5.4

[210] BMT WBM. "Williamtown - Salt Ash Floodplain Risk Management Study & Plan." (2017).

[211] Department of Planning, Industry, and Environment, NSW. "Hunter Valley Flood Mitigation Scheme: Fact Sheet." (2020).

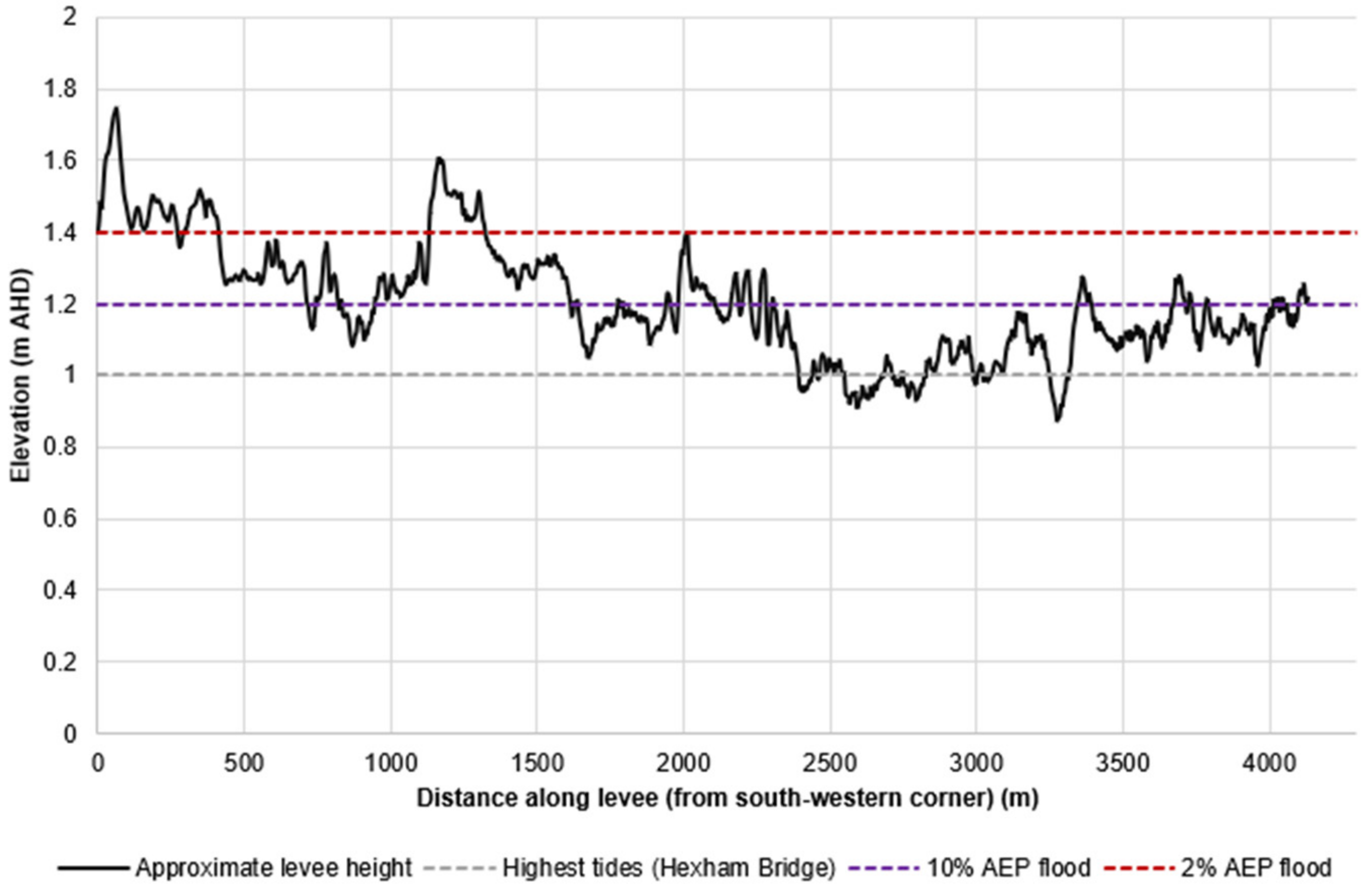

Figure 4.4: Approximate height of the Fullerton Cove levee (derived from GeoScience Australia DEM), compared to flood levels in Fullerton Cove.

Evidence of assets at risk

The Hunter River floodplain is highly developed, with significant infrastructure at risk during floods. The history of flooding in the Hunter River floodplain provides evidence of assets at risk due to flooding. Large flood events, such as the 1955 floods, resulted in loss of lives and infrastructure. The 1955 floods were estimated to have cost £2 billion pounds (1955 value in former currency) in damages, with more than 5,000 homes impacted by flooding, which led to the development of the Hunter Valley Flood Mitigation Scheme (HVFMS) and the construction of significant flood mitigation infrastructure[212]. While the HVFMS was designed to manage the risks of flooding in the broader Hunter region, there remains significant assets at risk during flood events. BMT WBM (2017)[213] estimated the damage costs from a flood in the Williamtown-Salt Ash area to be between $500,000 and $58 million for the 10 % AEP flood to the probable maximal flood, respectively. More wholistically, the present day Annual Average Damages (AAD) from flooding across the wider Hunter River catchment is approximately $200,000,000 per year[214]. This provides the necessary evidence that flood processes in the Hunter River floodplain are associated with significant risk to built infrastructure and assets.

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[212] Department of Planning, Industry, and Environment, NSW. "Hunter Valley Flood Mitigation Scheme: Fact Sheet." (2020).

[213] BMT WBM. "Williamtown - Salt Ash Floodplain Risk Management Study & Plan." (2017).

[214] Smith, G., et al. "Hydraulic and cost benefit assessment of the impact of climate change on the Hunter Valley Flood Mitigation Scheme - Summary Report." SGS Economics and Planning (2020).

Mechanisms for the restored ecosystem to reduce asset exposure

There are two primary ways that a restored coastal wetland can reduced the risk of asset exposure during floods:

Mechanism 1: provision of additional flood storage in broader catchment events

Description: encouraging floodplain inundation (e.g. overtopping of levees or flow through open channels and culverts) in a location that would otherwise be protected from flooding, reducing the volume of floodwater elsewhere in a catchment.

Consideration at the restored Tomago site: Flood storage areas are adjacent to major flood paths which hold (sometimes significant) volumes of water during flood events, reducing the volume of floodwaters elsewhere in the floodplain. During moderate to major flood events, flooding around Fullerton Cove is largely controlled by water levels in the main Hunter River, which are influenced by both rainfall in the wider Hunter River catchment and tidal water levels. During these events, increasing overbank flooding of areas like Tomago wetlands has the potential to provide flood storage. The Fullerton Cove Levee is cited to have been designed to overtop in 2 % AEP flood to act as a flood detention basin to provide additional protection to Newcastle[215,216]. However, localised low points in the levee (which pre-existed the restoration works), overtop in far more frequent events, including king tides[217] (see **Figure 4.4**). While overtopping of the Fullerton Cove Levee into Tomago Wetlands indicates it has the capacity to act as flood storage, it is noted that this mechanism for overbank flood storage pre-dates the restoration works. It is therefore not expected that any additional flood storage is provided by the wetland during riverine flood events and no additional modelling is recommended to quantify changes in flooding due to changes in flood storage.

Mechanism 2: improved conveyance of floodwaters during local catchment events

Description: improving the efficiency of floodwater drainage after flooding from direct upstream catchments can reduce flood levels during local catchment rainfall events which result in minor flooding.

Consideration at the restored Tomago site: During flooding caused by local rainfall events (e.g. rainfall in the local catchment of an area) conveyance of floodwaters from the floodplain into Fullerton Cove can influence flooding upstream of Tomago Wetlands. The majority of the local catchment draining into Tomago Wetlands drains out through the North-South Drain, and through the floodgate on the western side of the restoration site. The catchment for this drain is approximately 200 ha (bounded to the north by Tomago Road). Conveyance of local floodwaters is primarily influenced by:

- Tidal water levels in Fullerton Cove
- The conveyance capacity of the end of system floodgates (e.g. structures that connect the wetland to Fullerton Cove)
- The influence of channel friction

Tidal water levels in Fullerton Cove remain a major control of flow conveyance out of Tomago Wetlands. During local rainfall events, flow out of Tomago Wetlands through the two major floodgates is restricted to periods when water levels in Fullerton Cove are lower than water levels (typically only during low tides). Tidal water levels in Fullerton Cove are not impacted significantly

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[215] Russel, K., et al. "Tomago wetland rehabilitation project: integrated, innovative approaches." *NSW Coastal Conference* (2012).

[216] Rayner, D., & W. Glamore,. "Tidal Inundation and Wetland Restoration of Tomago Wetland: Hydrodynamic Modelling." Technical Report, *University of New South Wales Water Research Laboratory, Manly Vale, NSW* (2011).

[217] WBM Oceanics Australia. "Williamtown Salt Ash Flood Study" (2005).

by flow from the wetlands due to the negligible contribution to the tidal prism in the lower Hunter River. The restoration works are therefore considered to have not impacted the downstream tidal control in and out of the wetland. This mechanism for floodwater backing up behind the floodgates during high tides remains unchanged because of the restoration works. Monitoring of water levels upstream and downstream of the SmartGates in 2021 demonstrate that water levels in the North-South Drain continue to drain to low tide water levels post the restoration works.

The two major end of system structures at Tomago are the floodgates through the Fullerton Cove levee, that were modified to allow tidal flushing. These modifications to the gates were completed on the floodgate flaps only, no changes to the culverts were made. The conveyance capacity of these structures (flow from Tomago Wetlands into Fullerton Cove) therefore remained unchanged. Impacts of flooding to upstream properties from tidal inflows were managed through the installation of new, one-way floodgates at the upstream boundaries of the restoration area.

The final aspect which potentially impacts local flood conveyance is changes to friction in the channel system that conveys floodwater. While friction across the floodplain area may have increased due to the presence of wetland vegetation, compared to shorter pasture grasses, friction in the North-South Drain is likely to have decreased due to the capacity of salinity in managing freshwater weeds which often propagate in freshwater drainage systems in agricultural landscapes. However, the main North-South Drain was constructed as part of the HVFMS prior to the construction of the wetland and was therefore managed as a flood asset and had to be cleared of weeds to maintain flood mitigation capacity. It is therefore assumed that saline weed management within the main channel at Tomago Wetlands is unlikely to have significantly changed the flood conveyance of the main channel.

Concluding remarks

Tomago wetlands is in a region where flood processes present a significant risk to built infrastructure. However, the substantial flood mitigation infrastructure at the site (and across the wider Hunter River floodplain) pre-dates the restoration activities, including drains, floodgates and levee systems. The restoration activities were designed around the existing flood mitigation infrastructure, and the limited changes to the flood mitigation infrastructure (modification of the floodgates flaps to allow tidal flushing) are unlikely to have resulted in quantifiable changes to flood processes or reduction in flood levels during extreme events. Therefore, the account tables reflect no additional properties protected from flood processes.

Supplementary tables

Physical

		Supratidal swamp forest	Coastal saltmarshes	Mangroves	Muddy shoreline	Sandy shoreline	Seagrass meadow	Subtidal sand	Annual cropland	Constructed lacustrine wetland	Unattributed to the ecosystem	Total supply
	Units of measure	MFT1.2	MFT1.3	MFT1.2	MT1.2	MT1.3	M1.1	M1.7	T7.1	F3.2		
Flood mitigation services*	**Number of properties protected***										**0**	**0**

*Compared to pre-restoration infrastructure configuration

Monetary

		Supratidal swamp forest	Coastal saltmarshes	Mangroves	Muddy shoreline	Sandy shoreline	Seagrass meadow	Subtidal sand	Annual cropland	Constructed lacustrine wetland	Unattributed to the ecosystem	Total supply
	Units of measure	MFT1.2	MFT1.3	MFT1.2	MT1.2	MT1.3	M1.1	M1.7	T7.1	F3.2		
Flood mitigation services*	**Avoided Average Annual Damages ($/year)***										**0**	**0**

*Compared to pre-restoration infrastructure configuration

5. Restoration activities

Environmental protection & expenditure accounts

5.1 Restoration activities - physical, monetary

Intent and approach

The intent of the physical restoration activities accounts is to document the on-ground works completed onsite to achieve the restoration outcomes. This includes documentation of changes to infrastructure, such as the commissioning, decommissioning or modification of floodgates, the installation or removal of levees, and activities such as planting. Details of the works completed has been largely sourced from existing studies, first-hand experience and personnel communication with land managers, and analysis of aerial imagery. Where technical studies (e.g. numerical modelling) were completed, these have been included in the physical accounts as labour (days worked).

Restoration costs have been sourced from internal records and knowledge of staff at the UNSW Water Research Laboratory who have been extensively involved in the restoration since 2006, as well as consultation with project stakeholders. The costs include both technical advice and support (e.g. field trials of tidal flushing, hydrodynamic modelling used to help design the works to minimise impacts to adjacent landholders), and on-ground works (e.g. earthworks, fabrication/installation of floodgates). The costs consider the period of active restoration and on-ground works from the first field trials in 2006 to 2022. Costs prior to this, including time of individuals and groups who advocated for the project have not been included.

On-going site management and maintenance costs include some activities (e.g. weeding and pest control) that would have been required regardless of the restoration works. Due to the elapsed time since restoration, costs presented here are considered approximate only. In particular, regular site maintenance (e.g. regular weeding, inspections and maintenance of access) has been estimated based on approximate annual average costs, and assumed to be constant (adjusting for inflation) since the beginning of the restoration works. Funding for the restoration works at Tomago Wetland has come from a variety of sources, including (but not limited to):

- NSW National Parks and Wildlife Services
- NSW Government under the Marine Estate Strategy
- NSW Department of Primary Industries – Fisheries (including through Recreational Fishing Trust grants)
- Hunter Local Land Services
- NSW Department of Planning and Environment (including through their involvement in the Hunter Valley Flood Mitigation Scheme and Environmental Trust grants)

The restoration area considered in this study was owned by NSW National Parks and Wildlife Services prior to restoration, and no land acquisition has been considered in the costs.

Results

At Tomago Wetlands, restoration occurred in three distinct stages, progressively restoring tidal flows from west to east across the site, shown in **Figure 5.1.** Prior to on-ground works at each stage of the restoration, numerical modelling and project planning was completed to ensure the restoration works would successfully foster saltmarsh habitat, while minimising impacts to adjacent landholders. On-ground restoration activities included modification of multiple floodgates to allow controlled tidal flushing, the removal of one minor floodgate, the construction of 1.2 km of levee and the construction of two new one-way floodgates to mitigate impacts to upstream properties. Staging of restoration works allowed changes in hydrology to establish gradually and in an adaptive manner to ensure any potential impacts could be adequately managed.

Since 2015, on-going regular maintenance of the site has been managed by NSW National Parks, who estimate that approximately 130 days of staff time per year are spent managing Tomago Wetlands. This management includes pest/weed management, engagement of contractors, slashing, inspections and maintenance of infrastructure (including floodgates, drains, roads and bunds), liaising with neighbours and stakeholders. In addition to regular maintenance, a number of additional major works and studies have been completed between 2015 and 2022, including:

- Field UAV surveys to re-assess ground elevations and additional modelling to reassess trigger levels for the SmartGates and design new SwingGates to further minimise tidal inundation to upstream properties in 2018/2019
- Installation of upgraded SwingGates in 2020
- Investigation into impacts of drainage to upstream properties in 2021
- Field data collection at the North-South Drain and a floodplain conceptual model in 2022
- Installation and operation of new monitoring equipment (3 cameras and water level and salinity) in 2022

Mapping of restoration works, and tabulation of on-ground activities have been provided in the supplementary material. Since the accounts period extends over a 17-year timeframe, regular weeding and road/bund maintenance is assumed to have occurred across the entire site, and has not been explicitly mapped.

Reflection relative to the Guide

Completing the physical activities accounts for Tomago Wetlands highlights the need for good records to accurately account for changes that have occurred onsite. In this case, with the accounts being completed retrospectively, it can be difficult to access information on works completed up to 17-years ago. Similarly, while lump sum costs for the staged restoration works are available, identifying the timing of the costs has been approximated due to the retrospective nature of this project. Regular site management and maintenance costs vary year to year, however, a representative annual cost has been considered in these accounts due to the extended period. It is anticipated that many of these issues would be negated if the accounts were completed concurrently or immediately following the on-ground restoration works and annually thereafter.

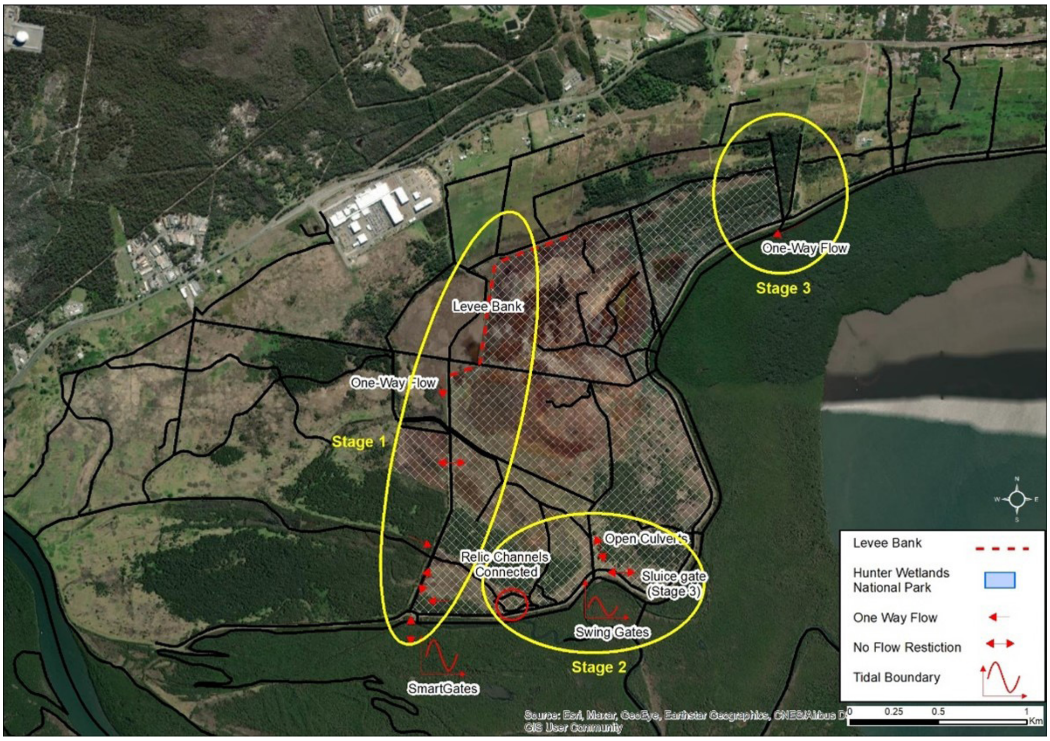

Figure 5.1: Summary of three stage restoration at Tomago Wetlands.

Project Timeline

2006-2007

Stage 1 restoration area - 'proof of concept' trials used to assess primary tidal restoration objectives of the site

- Numerical modelling completed to predict changes in hydrodynamics and inundation
- Modifiications to four of the five site's western culverts to include automated SmartGates (location 1) controlled using downstream water levels
- Installation of new one-way flaps on culverts to precent tidal inundation of upstream properties (location 6), and construction of 1.2 km levee on the north-west boundary

2008-2009

Monitoring - monitoring equipment installed to improve the understanding of the impacts of the restoration and to help guide further restoration

- Site monitoring including elevated telemetered camera, water levels, culvert discharges, and vegetation quadrant

2010-2011

Stage 2 restoration area - partial opening of eastern portion of site to tidal exchange and floodplain inundation

- Further numerical modelling to guide the implementation of Stage 2
- Modifications to site's eastern culverts (location 8) to include buoyancy controlled SwingGates at all four floodgates
- Installation of one-way flaps (location 9) to prevent tidal inundation of Stage 3 area
- Reconnection of relic drain to the main ring drain (location 13) with rock weir

2012-2015

Stage 3 restoration area - opening of far eastern component of site to tidal exchange and floodplain inundation

- Final round of numerical modelling of Stage 3 actions
- Installation of new one-way floodgates on north-eastern corner of the property to prevent tidal inundation of upstream properties (location 11). Separate to the restoration area, an additional property was purchased to the east of the wetland
- Modification of flap gates on eastern ring drain (location 9) to include sluice gates allowing tidal exchange to Stage 3 area
- Removal of one-way floodgate from floodgate on the western side of the north-south drain (location 5)

Figure 5.2: Timeline of restoration works at Tomago Wetlands.

Supporting information – physical restoration activities

The following figures and tables are supporting information for the physical restoration activities section. Details of the works completed has been largely sourced from existing studies[218,219,220,221] first-hand experience and personal communication with land managers, and analysis of aerial imagery.

Physical restoration activities

- **Figure 5.2** includes a timeline of the on-ground restoration works from Stage 1 to Stage 3 between 2006 and 2015.
- **Figure 5.3** and **Figure 5.4** are maps of the pre-restoration infrastructure onsite and the post-restoration infrastructure that supports the wetland habitats, respectively.
- **Table 5.1** which tabulates the on-ground restoration activities, excluding regular annual site management and maintenance.
- **Table 5.2** summarises representative annual site management and maintenance accounts. Note that weeding and maintenance of roads and bunds is assumed to have occurred across the entire site, and has not been explicitly mapped (as would be expected for accounts completed annual).

Monetary accounts

- **Table 5.3** details the major capital restoration costs for each stage and major capital costs post restoration (2015–2022, current price)
- **Table 5.4** tabulates the approximate annual site management and maintenance costs, in 2022 dollars. Note that these costs have been assumed to be constant since the restoration began.

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[218] Russell, K., et al. "Tomago wetland rehabilitation project: integrated, innovative approaches." *Proceedings of the 21st NSW Coastal Conference. Kiama, Australia* (2012).

[219] Rayner, D., et al. "Intertidal wetland vegetation dynamics under rising sea levels." *Science of The Total Environment*, 766 (2021), 144237. https://doi.org/10.1016/j.scitotenv.2020.144237

[220] Rayner, D., & W. Glamore. "Tidal Inundation and Wetland Restoration of Tomago Wetland: Hydrodynamic Modelling." T*echnical report, University of New South Wales Water Research Laboratory. Manly Vale, Australia* (2011).

[221] Glamore, W. C., et al. "Tomago Wetland Restoration; Numerical Modelling" (2005).

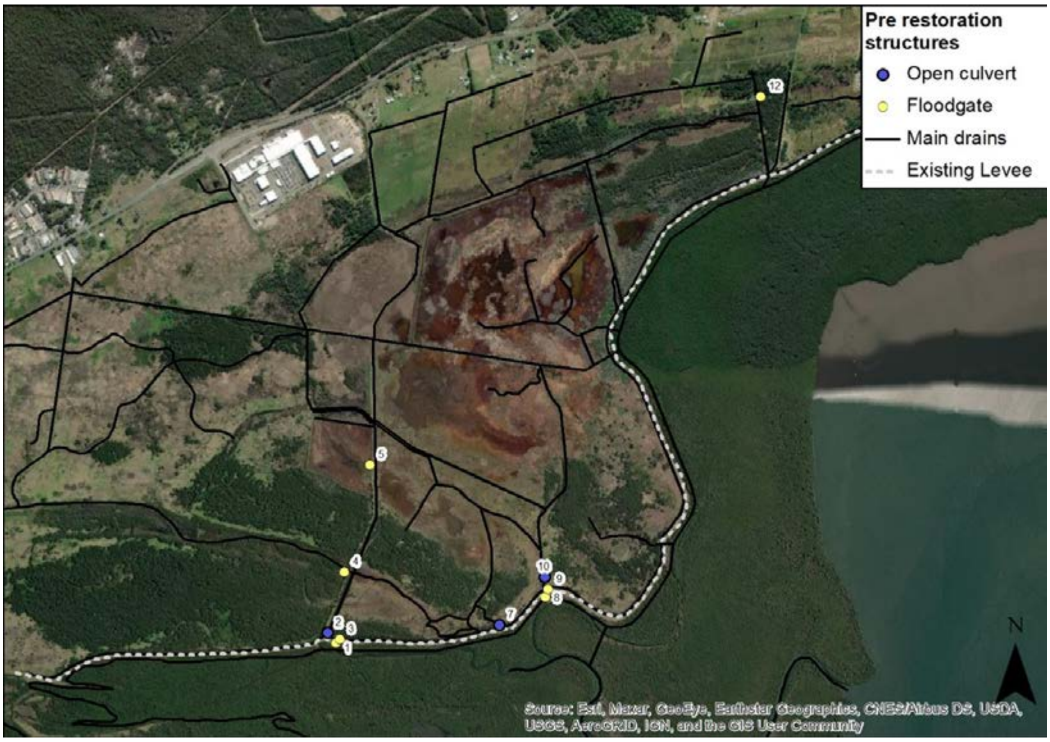

Figure 5.3: Infrastructure - pre restoration.

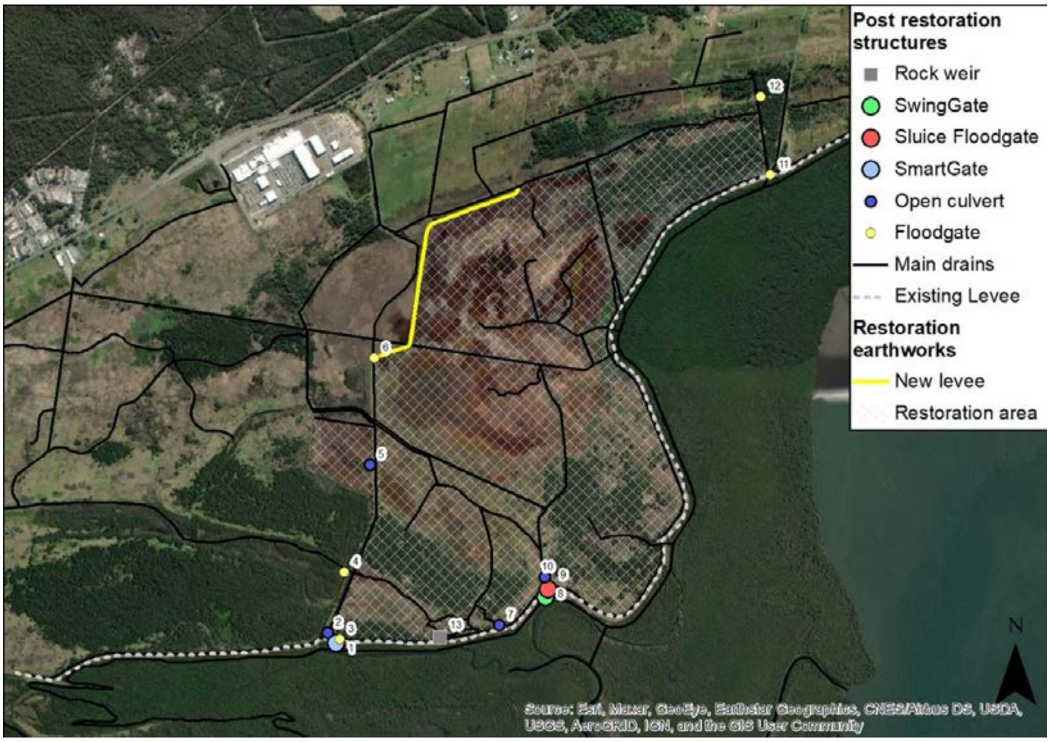

Figure 5.4: Infrastructure - post restoration.

Table 5.1: Physical restoration activities (excluding regular site management and maintenance).

Category	Item	Quantity	Comment
Physical landscape	Project area	300 ha	Consistent with site boundaries
Decommissioned/ Modified infrastructure	Number of floodgates modified	13	4 floodgate flaps (at one location) modified with a SmartGate (location 1) 8 floodgate flaps (at one location) modified with a SwingGate (location 8 – note that 4 flaps were installed during stage 2 of the restoration, and the same 4 were replaced in 2020 with a new design) 1 floodgate with sluice installed (location 9)
	Number of floodgates removed	1	1 floodgate flap removed (location 6)
Commissioned infrastructure	Number of floodgates commissioned	5	3 x Eastern floodgates and crossing installed (location 11) 2 x Floodgate installed on north-south drain (location 6)
	Number of weirs commissioned	1	Rock weir constructed to reconnect relic drain to ring drain (location 13)
	Length of levee/ bund constructed	1,220 m	Length measured from aerial imagery
Labour associated with technical support (including modelling, design and monitoring)	Number of days	337	Estimated based available records of hours spent on technical support and modelling

Table 5.2: Physical restoration activities (regular annual site management and maintenance only).

Category	Item	Quantity	Comment
Site management	Number of days	130/year	Estimate provided by NPWS. Assumed to be the same each year since the project began in lieu of yearly estimates Includes time for: – Inspection of infrastructure – Management of contracts and licenses – Liaising with adjacent landholders and stakeholders
Weeding and pest management	Area	300 ha	Assumed to be over the entire site boundaries over the course of year
Maintenance of access roads and bunds	Length of levee/bund maintained	~7,500 m	Assumed to have regular maintenance across all access roads and bunds (including Fullerton Cove levee). As this covers a 17-year period, this is reasonable, however annual accounts would be expected to map and measure locations requiring maintenance

Table 5.3: Restoration activity costs (excluding regular maintenance and site management, costs not CPI adjusted).

Stage	Indicative Timing	Type	Approximate Cost
1	2006 – 2009	Technical advice and support (e.g. modelling, design and advice)	$25,000
		On-ground costs, including: – Field trials – SmartGate modifications – Floodgate construction – Earthworks – Installation and management of monitoring equipment	$280,000
2	2010 – 2011	Technical advice and support (e.g. modelling, design and advice)	$55,000
		On-ground costs, including: – SwingGate modification – Earthworks	$65,000
3	2012 – 2015	Technical advice and support (e.g. modelling, design and advice)	$100,000
		On-ground costs: – Floodgate construction – Floodgate modification – Earthworks	$120,000
Post- active restoration period	2018	Technical advice and support, including: – UAV survey – SmartGate Triggers	$8,200
	2019	Technical advice and support, including: – Numerical modelling – Design of new SwingGates	$16,700
	2020	On-ground costs: – Construction and installation of new SwingGates	$64,500
	2021	Technical advice and support: – Investigations into impacts to adjacent properties	$10,000
	2022	Technical advice and support: – Additional monitoring (cameras, water level, salinity) – Field data collection of North-South Drain and bund elevation – Site conceptual model	$42,000
Total		**Technical advice and support**	**$256,900**
		On-ground costs	**$529,500**

Table 5.4: Physical restoration activity costs (regular annual site management and maintenance only, in 2022 dollars).

Category	Approximate costs	Comment
Land management labour costs	$51,000/year	Estimate provided by NPWS. Assumed to be the same each year since the project began in lieu of yearly estimates. Includes time for: – Inspection of infrastructure – Maintenance of access (e.g. slashing) – Management of contracts and licenses – Liaising with adjacent landholders and stakeholders – Meetings
Expenses for on-ground works	$132,000/year	Including use of machinery, contractors, consumables for regular on ground maintenance, pest and weed control etc.
Total	**$182,000/year**	

5.2 Restoration activities (monetary accounts)

Introduction

The restoration activities account includes the works carried out onsite to improve the ecosystem conditions including water quality and improving wildlife habitat. The restoration activities consisted of three phases for on-ground restoration works and the associated costs related activities are given in detail in the above section for physical restoration activities. The different activities for the staged restoration work on site to achieve the tidal connection to the Tomago wetland were continuous. Activities in Stage 1 (2006-2009) involved Installation of SmartGates, followed by stage 2 (2010-2011) SwingGates modification. In stage 3 (2012-2015) the restoration activities included technical advice and support and modification of standard floodgates with manual operated floodgate.

The restoration costs include costs with various ground works (e.g. mainly installing floodgates infrastructure and floodgates commissioned/ modified), site management and maintenance, and technical advice and support. In this case study, the monetary account provided an annual summary of all activities. Key informants who involved in the restoration project suggest the approximate annual site management and maintenance costs have been assumed to be constant since the restoration began.

Data available

The data for restoration costs has been provided by researchers at the UNSW Water Research Laboratory and collaborators who have been extensively involved in the Tomago restoration since 2006.

Results

The total restoration costs are reported annually after adjustments for inflation using CPI taking 2022 as the base year (Table 5.5). The annual summary included all the cost for on-ground restoration activities (mainly for installing floodgates infrastructure and floodgate commissioned), and site management and maintenance. The total cost of restoration is about AUD 4.1 million of which 75 % was spent for site management and the rest is accounted for as one-off costs. The approximate annual costs related to the three stages of restoration activities between 2006 and 2015 totaled about AUD 2.7 million. From that, the first stage accounts for 43 %, the second 19 % and the third 37 %. The costs for post-restoration (2015-2022) including surveys, modelling, swing-gates, investigation for upstream properties, and installing monitoring equipment, and filed work totalled about AUD 1.4 million.

Interpretation and discussion

Summary of restoration activities costs for on-ground activities, infrastructure, and consultation and advice support are given in Table 5.5. After value adjustments using Australian CPI, the on-ground restoration and maintenance and management activities are estimated to have cost of **4,127,027 AUD** between 2006 and 2022 in 2022 values. The restoration cost presented in the table is an aggregate annual restoration cost. To establish a detailed cost account by activities one would need to collect data by cost categories (e.g. capital costs, operating, monitoring etc.) and by year in future applications.

Table 5.5: Monetary account for restoration activity costs (in AUD 2022, base).

Year	Mangroves	Saltmarsh	Seagrass	Supratidal	Others	Total annual costs unadjusted (AUD)	CPI adjusted total annual cost (AUD)
2006						168,482	249,353
2007						306,381	444,252
2008*						171,939	238,995
2009*						174,263	236,998
2010						193,113	254,909
2011						207,746	265,915
2012						245,238	309,000
2013						181,780	223,589
2014						185,500	222,600
2015						208,822	246,410
2016						156,812	183,470
2017						159,825	183,799
2018						171,011	191,532
2019						182,161	202,199
2020						231,471	254,618
2021						181,670	194,387
2022						225,000	225,000
Total cost (AUD)						**3,351,214**	**4,127,027**
First stage (on-ground restoration) 2006-2009						821,065	1,169,599
Second stage (on-ground restoration) 2010-2011						400,859	520,824
Third stage (on-ground restoration) 2012-2015						821,340	1,001,599
Post-restoration						1,307,950	1,435,005

*The costs for 2008 and 2009 are monitoring costs

6. General discussion and lessons learned

Overall, despite some limitations due to only using existing datasets, this case study can be considered a successful application of the process and advice offered within the Guide to Measuring and Accounting for the Benefits of Restoring Coastal Blue Carbon Ecosystems The two key learnings from applying the Guide to this case study were:

1. Collecting data following the process as outlined in the Guide (as opposed to doing this retrospectively using available data) is ideal for compiling project-level restoration project accounts.
2. Higher detail methods (and therefore higher cost) can greatly influence the outcomes of project-level accounts, particularly at smaller sites. This was clear from the comparisons done in this case study from extent, condition and carbon accounts.

The Tomago Wetland restoration area is one well known to the project team and with the advantage of high data availability compared to areas that may be of interest to future users of the Guide. As a result, some aspects of the process (e.g. extent, condition, carbon, and fisheries) could make use of detailed datasets that may not be available to potential users of the Guide.

The case study allows us to trial low cost, low data-need options for these aspects of Guide implementation, and compare them with more detailed methods that rely on datasets specific to the Tomago area. This was done for extent and condition, as well as for carbon. Overall, both low and high-detail methods were able to produce SEEA accounts, albeit the more detailed methods reported significantly higher changes due to restoration than the less detailed options. For example, the more detailed extent methodology estimated extent changes of around 460 % of blue carbon ecosystems than that of the less detailed methodology[222]. Carbon abatement and carbon stock estimates were around 30 % and 100 % higher under more detailed methodologies than less detailed methodologies, reflecting conservative assumptions necessary to avoid over-estimates.

Perhaps the most conceptually-challenging aspect of measurement in this case study has been estimating ecosystem condition changes. A clear and defensible set of condition indicators will be needed by project proponents to ensure the integrity of restoration actions over time. While many aspects of condition can be estimated, it is challenging to define and then measure a limited set of indicators that appropriately encompass the relevant changes that a restoration project produces, particularly as some changes will inevitably be unpredictable. This has been exacerbated in this case study as we were restricted to data inputs that were available at project commencement.

In relation to how well the SEEA performs as a reporting method, it has a clear and repeatable logic that should be able to accommodate most of

[222] As the nationally-consistent extent methodology relies on satellite imagery, it is expected that future users will benefit from higher resolution imagery than we used in this project (which backcasted to 2005).

the types of impacts that a restoration project is likely to produce. There are some methodological considerations, however:

- Carbon accounting methodologies like BlueCAM typical estimate the accrual of carbon sequestration over a given time period (say, 25 years), while the SEEA typically reports annual flows and changes in stocks.
- One aspect of carbon accounting is to estimate changes in emissions due to different land use activities. In the case of the Tomago case study, changing land use from pasture to blue carbon ecosystems is estimated to emit between 3,000 and 7,000 t CO_2e emissions over the analysis period. The SEEA does not conceptually account for avoided emissions and this impact is inconsistent with SEEA reporting, however there is likely scope for SEEA to do this with modification.
- The SEEA recommends reporting ecosystem condition data using mean values. The project team prefers to report the area within the project boundary that increased in condition and that which decreased in condition, on the basis that reporting mean data across the restoration area can produce misleading results (e.g. if 50 % of area increases in condition and 50 % declines, the mean will report no change).
- Economic data within the SEEA-EA is focused on exchange values, while some welfare values (particularly relating to community preferences and willingness to pay for restoration activities) less clearly framed with this reporting system. For some decision-making processes such as cost-benefit analysis using whole-of-community costs and benefits, welfare values should be included in decision-making. Please refer to the Guide for further information comparing economic approaches[224].
- For restoration costs, SEEA tables seek to report costs attributable to the different ecosystems within the restoration area, on the basis that this may inform readers of the cost-effectiveness of different restoration actions and the cost-effectiveness of restoring different ecosystem types. However, restoration actions are often undertaken holistically regardless of the specific ecosystem composition, and proportioning costs by share of ecosystem extent may mislead readers as to the cost-effectiveness of restoring different ecosystems within a project.

An additional consideration of using SEEA tables is their user-friendliness for those reading them to understand the changes produced by a restoration project. As can be seen in the tables in **Section 8**, the format of SEEA accounts tables involves presentation of many columns and rows that may be empty of data for a restoration project, resulting in long and wide tables that can be difficult to interpret for a first time reader. Visual tools that convey that information (such as maps or graphs) may be more accessible to a broader audience and can be used in addition to account tables.

One lesson to consider from this case study is the cost of implementation of the different components of this work and the overall cost of implementation if all aspects were included in a similar project assessment. We do not expect users of the Guide to implement every component of the Guide; rather, we expect users will focus on the key components of relevance to their project. However, it seems likely that implementation will include a similar number of components: ecosystem extent and condition, plus at least three ecosystem services (such as carbon, cultural services such as recreational fishing and/or bird watching, and perhaps fish productivity). As such, it is likely that an assessment including overall management and drafting of results may cost in the order of $150 k - $500 k per accounting year, depending on high or low cost approaches used. Estimating fewer components would of course involve lower costs, however data collection must be sufficient for any certification that proponents may seek to obtain.

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[223] See, for example, Table 21 on page 98 of https://seea.un.org/sites/seea.un.org/files/publications/guidancebiomodelling_v36_30032022_web.pdf.

[224] Carnell, P., et al. "A Guide to Measuring and Accounting for the Benefits of Restoring Coastal Blue Carbon Ecosystems." *Report to DCCEEW* (2023).

7. Glossary

Glossary of relevant Ecosystem Services from SEEA, adapted from SEEA Table 6.3[225]

Ecosystem Service as described in case study	Ecosystem Service		Description
Provisioning services			
Fisheries biomass provisioning service	Biomass provisioning services	Wild fish and other natural aquatic biomass provisioning services	Wild fish and other natural aquatic biomass provisioning services are the ecosystem contributions to the growth of fish and other aquatic biomass that are captured in uncultivated production contexts by economic units for various uses, primarily food production. This is a final ecosystem service.
Fisheries nursery services	Other provisioning services		Nursery population and habitat maintenance services are the ecosystem contributions necessary for sustaining populations of species that economic units ultimately use or enjoy either through the maintenance of habitats (e.g. for nurseries or migration) or the protection of natural gene pools. This service is an intermediate service and may input to a number of different final ecosystem services including biomass provision and recreation-related services.
Regulating and maintenance services			
Flood control services	Flood control services	River flood mitigation services	River flood mitigation services are the ecosystem contributions of riparian vegetation which provides structure and a physical barrier to high water levels and thus mitigates the impacts of floods on local communities. River flood mitigation services will be supplied together with peak flow mitigation services in providing the benefit of flood protection. This is a final ecosystem service.
Carbon sequestration & emissions	Global climate regulation services		Global climate regulation services are the ecosystem contributions to reducing concentrations of GHG in the atmosphere through the removal (sequestration) of carbon from the atmosphere and the retention (storage) of carbon in ecosystems. These services support the regulation of the chemical composition of the atmosphere and oceans. This is a final ecosystem service.
Cultural services			
Recreational 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.

225 United Nations. "System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA)". (2021). https://seea.un.org/ecosystem-accounting.

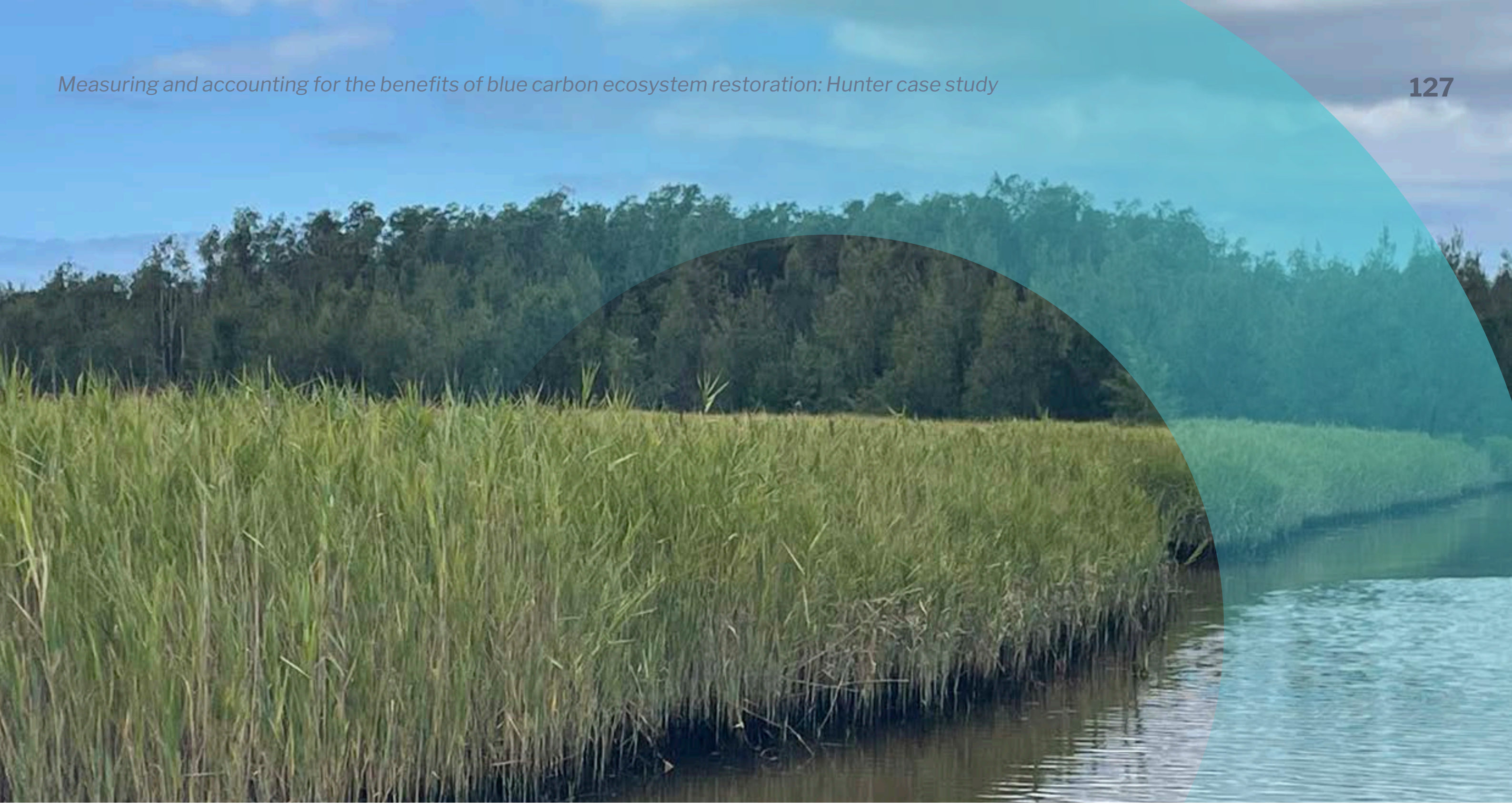
Glossary of terms

Term	Definition
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences.
Abiotic	Not from living organisms, only in the physical or chemical realm.
Australian carbon credit units (ACCU)	ACCUs offers landholders, communities and businesses the opportunity to run projects in Australia that avoid the release of greenhouse gas emissions or remove and sequester carbon from the atmosphere.
Acid Sulfate Soils (ASS)	Naturally occurring soils and sediments containing iron sulphides, most commonly pyrite. When ASS are exposed to air the iron sulphides in the soil react with oxygen and water to produce a variety of iron compounds and sulfuric acid. Initially a chemical reaction, the process is accelerated by soil bacteria.
Activities	Activities that occur in or near ecosystems that have impacts on the system, generally with economic benefits (for example, fishing).
Above Ground Biomass (AGB)	Living vegetation above the soil, including stem, stump, branches, bark, seeds, and foliage.
Annual Average Damage (AAD)	Calculated equivalent annual equivalent expense if hazard damages occurred evenly through time.
ArcMap	Main component of Esri's ArcGIS suite of geospatial processing programs, and is used primarily to view, edit, create, and analyse geospatial data.
Annual Exceedance Probability (AEP)	The probability (measured as a percentage) that a given rainfall total accumulated over a given duration will be exceeded in any one year.
Australian height data (AHD)	The Australian Height Datum (AHD) is the official national vertical datum for Australia and refers to Australian Height Datum 1971 (AHD71; Australian mainland) and Australian Height Datum (Tasmania) 1983 (AHD-TAS83).
Assets	An item or service that has value which is measured in the accounts.
Biodiversity	The diversity of life found within an area.
Biomass	The mass of biological matter, generally expressed in kg or t.
Biotic	Produced from living organisms.
Blue Accounting Model (BlueCAM)	A model used to estimate carbon stocks in a wetland ecosystem.
Blue Carbon Ecosystems	Ecosystems that contain blue carbon, which is stored atmospheric or oceanic carbon.
Carbon sequestration	The process of capturing and storing atmospheric carbon dioxide, often mitigating greenhouse emissions.
Carbon Estimation Area (CEA)	A stratum of the Project Area; land which is homogenous for the purpose of abatement calculations, has consistent biophysical characteristics and is established and managed in a consistent way. CEAs may be defined by a single CEA Polygon or, where a specific method allows, more than one CEA Polygon (see Split CEA).
Coastal protection	Physical protection provided by habitats to human developments.
Compositional state	The composition of an ecosystem, usually referring to plant or animal communities and their diversity.
Conceptual model	Simplified flow chart outlining interactions between different factors relevant to the system examined.
DCCEEW	Commonwealth Department of Climate Change, Energy, the Environment and Water.
Digital Earth Australia (DEA) sandbox	The Digital Earth Australia (DEA) Sandbox is a learning and analysis environment for getting started with DEA data and our Open Data Cube.
Digital elevation model (DEM)	A Digital Elevation Model (DEM) is a representation of the bare ground (bare earth) topographic surface of the Earth excluding trees, buildings, and any other surface objects.

Term	Definition
Ecosystem condition	The quality of the ecosystem measured in terms of its abiotic, biotic and landscape/seascape characteristics. Successfully restored habitats should see their condition improve.
Ecosystem conversion	Amount of change in restored habitats before and after restoration activities.
Ecosystem extent	Spatial area covered by an ecosystem, expressed in hectares (Ha), m^2 or km^2. Also 'size of ecosystem asset'.
Ecosystem service	The many and varied benefits to humans provided by the natural environment and from healthy ecosystems. For example, the fish they produce that are then consumed by fisheries.
eCognition	Trimble eCognition software is used by GIS professionals, remote sensing experts & data scientists to automate geospatial data analytics.
Ecotone	A transitional area of vegetation between two different plant communities, for example between saltmarshes and mangroves.
Environmental Economic Accounting (EEA)	A framework for organising statistical information to help decision-makers better understand how the economy and the environment interact.
Environmental economic account	Accounts used to value ecosystems, usually comprised of an ecosystem extent account and an ecosystem condition account.
Environmental economic accounting	Framework used to compile information linking environmental factors to economics.
Emissions trading register (ETR)	An online database that issues, records, and tracks the carbon units that are exchanged within market mechanisms or financed through Results-Based Climate Finance programs.
Fine benthic organic matter (FBOM)	Deposited on the stream bottom (i.e. fine benthic organic matter) can vary greatly between stream habitats (e.g. pools and riffles) and is a key food for deposit feeders (analogous to microphytobenthos).
First Nations ecosystem services	Services provided by natural habitats to First Nations people.
Fisheries biomass provisioning service	The fish product (e.g. fishes and crustaceans) produced from ecosystem services that is caught and sold by fisheries.
Flows	Ecosystem services in environmental accounting, usually between ecosystem assets and economic units.
Food web	A more complicated version of a food chain that includes all feeding interactions between organisms in an ecosystem.
Functional state	The function of the community.
Geographic Information Systems (GIS)	Software systems used to process spatial information, to create maps, for example.
Global climate regulation	Activities, natural or human-caused, that help regulate the climate, generally through lowering atmospheric greenhouse gases.
Habitat maintenance	Services provided by natural habitats to themselves that are required for ecosystem function.
Highest astronomical tide (HAT)	Defined as the highest level which can be predicted to occur under average meteorological conditions and any combination of astronomical conditions.
Hunter Valley Flood Mitigation Scheme (HVFMS)	State owned engineering work, designed to lessen the effects of flooding on both rural and urban areas, reducing flood damage by modifying flood behaviour.
Indigenous Protected Areas (IPA)	Areas of land and sea Country managed by First Nations groups in accordance with Traditional Owners' objectives.
Hydrodynamic regime	Patterns in water flow within or across an ecosystem, for example tidal patterns.
Landsat	Earth observation satellite system run by NASA (digital remote sensed data).
Lowest astronomical tide (LAT)	Defined as the lowest level which can be predicted to occur under average meteorological conditions and any combination of astronomical conditions.

Term	Definition
Light detection and ranging (LiDAR)	Also called 3D laser scanning, LiDAR is a method for determining ranges by targeting an object or surface with a laser and measuring the time for the reflected light to return to the received.
Modified Normalised Difference Wetness Index (MNDWI)	Uses green and short-wave infrared band pixel values to enhance open water features in GIS applications.
Modelling	Extrapolating patterns, either between known data points, or into the future.
Monetary accounts	Accounts that measure the value of ecosystems for society.
Monitoring	Repetitive assessments of habitat condition, usually conducted annually or every 5 years.
Nursery population	Role of habitats for assisting the growth of young animals.
Object-based image analysis (OBIA)	A type of image analysis that groups cells into objects (i.e. vectors) based on their spectral, geometrical and spatial properties to partition and classify Earth observation data.
Orthomosaic	The output from a process where a number of overlapping photos (e.g. from a drone or aerial camera) are stitched together with distortions removed to create a complete and continuous image representation or map of a portion of the earth.
Physical accounts	Accounts that measure the physical distribution of ecosystems, for example habitat extent or productivity.
Pools	Components of an ecosystem that can 'store' carbon.
Primary data collection	Information requiring boots on the ground at the site of restoration to assess, data not currently existing elsewhere.
Project scoping	Determining the size of the project, both in time and space.
QGIS	QGIS is a free and open-source cross-platform desktop geographic information system (GIS) application that supports viewing, editing, printing, and analysis of geospatial data.
Ramsar	The Ramsar Convention on Wetlands of International Importance Especially as Waterfowl Habitat is an international treaty for the conservation and sustainable use of Ramsar sites (wetlands). It is also known as the Convention on Wetlands. It is named after the city of Ramsar in Iran, where the convention was signed in 1971.
Reference level	The value of a variable at the reference condition, against which it is meaningful to compare past, present or future measured values of the variable.
Reference sites	Sites with similar habitat at the restoration site, used to assess relative changes as being caused by restoration activities.
Regional multipliers	An expenditure that leads to broader economic benefits, for example the value of 1 kg of prawns caught leads to broader economic benefits from processing, transport etc.
Remote sensing	Process of detecting and monitoring the physical characteristics of an area using aircraft or satellites, without physically interacting with the habitat.
Remotely-piloted aircraft (RPA), or UAV	Aircraft flown without a person on-board, also called "drone" or Unmanned Aerial Vehicle (UAV).
Restoration project	A project aiming to undo damage caused by human activities within a given area, usually trying to revert to conditions pre-human influence.
SEEA	System of Environmental Economic Accounting A formal framework developed by the UN for valuing ecosystem services.
SEEA-EA	System of Environmental Economic Accounting Ecosystem Accounting.
SIMMR	A statistical package in R designed to solve mixing equations for stable isotopic data within a Bayesian framework.

Term	Definition
Spatial coverage	Area covered by the project.
Spatial resolution	How easy it is to distinguish two neighbouring structures as separated, higher is usually better but comes at a cost of data maintenance issues. Usually expressed in m or km.
Stable isotopes	Naturally-occurring elements (e.g. Carbon) that do not decay like radioisotopes.
Stakeholder	A stakeholder is either an individual, group or organization that's impacted by the outcome of a project or a business venture. Stakeholders have an interest in the success of the project and can be within or outside the organization that's sponsoring the project.
Statistical	Summarising numbers in a way that is objective.
Stocks	Natural resources or land, such as fish stocks.
Supply and use tables	Record flows of goods and services, including ecosystem services, between economic units and the environment, including ecosystems
Supratidal forest	Forest occurring on a tidal flat above the level of mean high water for spring tides, 'splash zone'.
Terms of Reference	The prescribed temporal coverage of the Hunter case study was to have two snapshots; one representing the site before intervention, and one after. The ecosystem services to be considered included: Fish nursery, Fish biomass provisioning, Recreational activities, Carbon sequestration and emissions, and Coastal protection.
Trophic enrichment factor (TEF)	A parameter reflecting the difference in isotopic ratio between a consumer's tissues and diet, used in isotopic ecology and paleoecology to track dietary habits.
Temporal coverage	Historical time across which data will be collected.
The Guide	A Guide to Measuring and Accounting for the Benefits of Restoring Coastal Blue Carbon Ecosystems, 2023.
Universal Transverse Mercator (UTM)	A map projection system for assigning coordinates to locations on the surface of the Earth.
Validation	Assessing the accuracy or uncertainty of higher-level remote sensing products with analytical reference data (such as corresponding ground and field measurements or using experts to verify).
Water purification service	Processes that increase the quality of the water, for example often reducing levels of pollutants.
Woody Vegetation Cover Fraction (WCF)	Vertical projection area of vegetation cover index used in remote sensing applications.
World Geodetic System (WGS)	A standard used in cartography, geodesy, and satellite navigation including GPS. The current version, WGS 84, defines an Earth-centred, Earth-fixed coordinate system and a geodetic datum, and also describes the associated Earth Gravitational Model (EGM) and World Magnetic Model (WMM).
Willingness to Pay (WTP)	The maximum price a customer or consumer is willing to pay for a product or service.



8. SEEA-based accounts

Below are a set of SEEA-based account tables that draw upon the analysis done in previous sections, and report in a structure that is broadly consistent with the SEEA-EA reporting structure. Where tables do not have relevant data they have been left blank to illustrate what could be presented (for example, flood mitigation).

8.1 Ecosystem extent account

Table 8.1: Ecosystem extent account

Realm	**Marine-Freshwater-Terrestrial**			**Marine**		**Marine-Terrestrial**		**Terrestrial**	**Freshwater**	
Biome	**MFT1 Brackish tidal**			**M1 Marine shelf**		**MT1 Shorelines biome**		**T7 Intensive land use**	**F3 Artifical wetlands**	
Selected Ecosystem Functional Group (EFG)	Supratidal swamp forest MFT1.2* ha	Saltmarsh MFT1.3 ha	Mangroves MFT1.2 ha	Seagrass MFT1.1 ha	Subtidal sand beds MFT1.7 ha	Muddy shorelines MFT1.2 ha	Sandy shorelines MFT1.3 ha	Other land covers T7.1 ha	Constructed lacustrine wetlands F3.2 ha	**Total ecosystem extent** ha
Opening extent 2005 (pre-restoration)	33.12	102.51	3.96	0	0	0	0	159.21	0	298.80
Additions										
Managed expansion	10.44	35.46								
Unmanaged expansion						45.09				
Total additions	*10.44*	*35.46*	*0*	*0*	*0*	*45.09*	*0*	*0*	*0*	*90.99*
Reductions										
Managed reduction										
Unmanaged reduction								90.99		
Total reductions	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*90.99*	*0*	*90.99*
Net change	10.44	35.46	0	0	0	45.09		-90.99		0
Closing extent	43.46	137.97	3.96	0	0	45.09	0	68.22	0	298.80

8.1 Ecosystem condition account

Table 8.2: Ecosystem condition indicator account[226]. *Continued over page.*

SEEA Ecosystem Condition Typology Class			Indicators				
			Descriptor	**Measurement unit**	**Opening value**	**Closing value**	**Change in indicator**
Mangrove	Abiotic		Landscape wetness	Spectral index, rescaled (0-1)	0.26 (0.01)	0.28 (0.01)	0.02
	Biotic	Structural state	Age since restoration activities	Years	-	16.93	0
			Vegetation cover	% cover, rescaled (0-1)	0.59 (0.04)	0.58 (0.05)	0.05
			Above-ground biomass	Mg ha^{-1}	60.32 (27.06)	60.45 (22.09)	0.13
		Functional state	Vegetation greenness	Spectral index, rescaled (0-1)	0.85 (0.02)	0.85 (0.02)	0
	Landscape/seascape characteristics		Connectivity of ecosystem	Index, rescaled (0-1)	0.23 (0.11)	0.23 (0.11)	0
Saltmarsh	Abiotic		Landscape wetness	Spectral index, rescaled (0-1)	0.22 (0.01)	0.23 (0.04)	0.01
	Biotic	Structural state	Age since restoration activities	Years	-	10.21 (3.96)	-
			Vegetation cover	% cover, rescaled (0-1)	0.7 (0.07)	0.6 (0.09)	-0.1
			Above-ground biomass	Mg ha^{-1}	7.57 (14.9)	3 (9.49)	-4.57

[226] Opening account year = 2005, closing account year = 2021). Values are mean of all cells in restoration activity boundary, values brackets indicate standard deviation. Comparison area for opening and closing mean values is the mutually inclusive area of the ecosystem type (i.e. where mangrove was present in both pre- and post-restoration activities). *unreliable estimates from datasets and not included.

Table 8.2: cont.

SEEA Ecosystem Condition Typology Class			Indicators				
			Descriptor	**Measurement unit**	**Opening value**	**Closing value**	**Change in indicator**
Saltmarsh	Biotic	Functional state	Vegetation greenness	Spectral index, rescale (0-1)	0.79 (0.03)	0.77 (0.03)	-0.02
	Landscape/seascape characteristics		Connectivity of ecosystem	Index, rescaled (0-1)	0.51 (0.31)	0.54 (0.3)	0.03
Supratidal forests	Abiotic		Landscape wetness	Spectral index, rescaled (0-1)	0.25 (0.01)	0.28 (0.04)	0.03
	Biotic	Structural state	Age since restoration activities	Years	-	9.88 (5.12)	-
			Vegetation cover	% cover, rescaled (0-1)	0.59 (0.05)	0.67 (0.05)	0.08
			Above-ground biomass	Mg ha^{-1}	56.42 (32.34)	54.75 (27.09)	-1.67
		Functional state	Vegetation greenness	Spectral index, rescaled (0-1)	0.86 (0.01)	0.88 (0.01)	0.02
	Landscape/seascape characteristics		Connectivity of ecosystem	Index, rescaled (0-1)	0.47 (0.29)	0.52 (0.32)	0.05
Muddy shorelines	Abiotic		Landscape wetness	Spectral index, rescaled (0-1)	0.23 (0.02)	0.25 (0.02)	0.02
	Biotic	Structural state	Age since restoration activities	Years	-	15.73 (1.24)	-
			Vegetation cover	% cover, rescaled (0-1)	0.35 (0.13)	0.47 (0.15)	0.12
			Above-ground cover	Mg ha^{-1}	13.23 (20.02)	9.69 (19.3)	-3.54
		Functional state	Vegetation greenness	Spectral index, rescaled (0-1)	0.81 (0.03)	0.83 (0.04)	0.02

Table 8.2: cont.

SEEA Ecosystem Condition Typology Class			Indicators				
			Descriptor	**Measurement unit**	**Opening value**	**Closing value**	**Change in indicator**
Muddy shorelines	Landscape/seascape characteristics		Connectivity of ecosystem	Index, rescaled (0-1)	0	0.5 (0.31)	0.5
Other land covers	Abiotic		Landscape wetness	Spectral index, rescaled (0-1)	0.23 (0.02)	0.25 (0.02)	0.02
	Biotic	Structural state	Age since restoration activities	Years	-	15.73 (1.24)	-
			Vegetation cover	% cover, rescaled (0-1)	0.35 (0.13)	0.47 (0.15)	0.12
			Above-ground biomass	Mg ha^{-1}	13.23 (20.02)	9.69 (19.3)	-3.54
		Functional state	Vegetation greenness	Spectral index, rescaled (0-1)	0.81 (0.03)	0.83 (0.04)	0.02
	Landscape/seascape characteristics		Connectivity of ecosystem	Index, rescaled (0-1)	0.59 (0.31)	0.41 (0.26)	-0.18

Table 8.3: Ecosystem condition indicator account (opening account year = 2005, closing account year = 2021). Values for connectivity of ecosystem are mean of all cells in restoration activity boundary, values brackets indicate standard deviation. Comparison area for opening and closing mean values is the mutually inclusive area of the ecosystem type (i.e. where mangrove was present in both pre- and post-restoration activities. Note that for vegetation cover, biomass, greenness and wetness this is reported as change in hectare area for descriptor (i.e. opening value = area gained or maintained in value of descriptor, closing value = area loss in value of descriptor, change in indicator = net change in area for condition indicator). * unreliable estimates from datasets and not included. *Continued over page.*

SEEA Ecosystem Condition Typology Class			Indicators				
			Descriptor	**Measurement unit**	**Increase in indicator value/ Opening value**	**Decrease in indicator value/ Closing value**	**Change in indicator**
Mangrove	Abiotic		Landscape wetness	Hectares	4	0	4
	Biotic	Structural state	Age since restoration activities	Years	-	16.93	0
			Vegetation cover	Hectares	2	2	0
			Above-ground biomass	Hectares	2	2	0
		Functional state	Vegetation greenness	Hectares	1	3	-2
	Landscape/seascape characteristics		Connectivity of ecosystem	Index, rescaled (0-1)	0.23 (0.11)	0.23 (0.11)	0
Saltmarsh	Abiotic		Landscape wetness	Hectares	53	31	22
	Biotic	Structural state	Age since restoration activities	Years	-	10.21 (3.96)	-
			Vegetation cover	Hectares	19	65	-46

Table 8.3: cont.

SEEA Ecosystem Condition Typology Class			Indicators				
			Descriptor	**Measurement unit**	**Opening value**	**Closing value**	**Change in indicator**
Saltmarsh	Biotic	Structural state	Above-ground biomass	Hectares	51	32	19
		Functional state	Vegetation greenness	Hectares	29	54	-25
	Landscape/seascape characteristics		Connectivity of ecosystem	Index, rescaled (0-1)	0.51 (0.31)	0.54 (0.3)	0.03
Supratidal forests	Abiotic		Landscape wetness	Hectares	19	0	19
	Biotic	Structural state	Age since restoration activities	Years	-	9.88 (5.12)	-
			Vegetation cover	Hectares	18	1	17
			Above-ground biomass	Hectares	10	9	1
		Functional state	Vegetation greenness	Hectares	18	1	17
	Landscape/seascape characteristics		Connectivity of ecosystem	Index, rescaled (0-1)	0.47 (0.29)	0.52 (0.32)	0.05
Waterbodies/ Mudflats	Abiotic		Landscape wetness	Hectares	-	-	-
	Biotic	Structural state	Age since restoration activities	Years	-	6.82 (2)	-
			Vegetation cover	Hectares	-	-	-
			Above-ground cover	Hectares	-	-	-

Table 8.3: cont.

SEEA Ecosystem Condition Typology Class			Indicators				
			Descriptor	**Measurement unit**	**Opening value**	**Closing value**	**Change in indicator**
Waterbodies/ mudflats	Landscape/seascape characteristics		Connectivity of ecosystem	Index, rescaled (0-1)	0	0.5 (0.31)	0.5
Other land covers	Abiotic		Landscape wetness	Hectares	53	9	44
	Biotic	Structural state	Age since restoration activities	Years	-	15.73 (1.24)	-
			Vegetation cover	Hectares	48	14	34
			Above-ground biomass	Hectares	30	31	-1
		Functional state	Vegetation greenness	Hectares	45	16	29
	Landscape/seascape characteristics		Connectivity of ecosystem	Index, rescaled (0-1)	0.59 (0.31)	0.41 (0.26)	-0.18

Table 8.4: Change in land cover type, area and associated vegetation biomass stocks (above-ground biomass, AGB) derived from Blue Cam. The difference in AGB indicates significant gain (blue), loss (red) and negligible change (orange).

Pre-restoration Land cover	**Post-restoration** Land cover	**Area (ha)**	**Pre-restoration** Vegetation biomass stocks - baseline AGB t DW ha^{-1}	**Post-restoration** Vegetation biomass stocks - baseline AGB t DW ha^{-1}	**Difference in AGB**
Supratidal forest	Supratidal forest	20.69	200.00	242.40	42.40
Supratidal forest	Saltmarsh	7.94	200.00	122.70	-77.30
Supratidal forest	Grass	0.06	200.00	120.00	-80.00
Supratidal forest	Mudflats and ponds	1.06	200.00	120.00	-80.00
Grass	Grass	2.73	10.50	6.30	-4.20
Grass	Mudflats and ponds	23.59	10.50	6.30	-4.20
Grass	Saltmarsh	52.81	10.50	9.00	-1.50
Grass	Supratidal forest	31.38	10.50	37.70	27.20
Dry scrub or cleared land	Grass	0.50	10.50	6.30	-4.20
Dry scrub or cleared land	Mudflats and ponds	38.28	10.50	6.30	-4.20
Dry scrub or cleared land	Saltmarsh	80.06	10.50	9.00	-1.50
Dry scrub or cleared land	Supratidal forest	34.35	10.50	37.70	27.20

Table 8.5: Connectivity before and after restoration activities.

Mean connectivity (0-1)	**Pre-restoration**	Class 1 (dry scrub or cleared land)	0.78
		Class 2 (grass)	0.70
		Class 3 (supratidal forests)	0.56
		Class 4 (waterbodies)	0.43
	Post-restoration	Class 1 (grass)	0.74
		Class 2 (mudflats and ponds)	0.34
		Class 3 (saltmarsh)	0.75
		Class 4 (supratidal forests)	0.38
		Class 5 (waterbodies)	0.72

8.3 Physical ecosystem service account

Table 8.6: Ecosystem services supply and use account in physical terms – supply table, post-restoration. *Continued over page.*

							Marine-Freshwater-Terrestrial			Marine		Marine-Terrestrial		Terrestrial	Freshwater	Total
		Industry				Sector	MFT1 Brackish tidal			M1 Marine shelf		MT1 Shorelines biome		T7 Intensive land use	F3 Artifical wetlands	
	Units of measure	Agriculture, forestry and fishing	Other industry	Total industry	Households	Government	Supratidal swamp forest	Saltmarsh	Mangroves	Seagrass	Subtidal sand beds	Muddy shorelines	Sandy shorelines	Other land covers	Constructed lacustrine wetlands	
SUPPLY							MFT1.2*	MFT1.3	MFT1.2	M1.1	M1.7	MT1.2	MT1.3	T7.1	F3.2	
Provisioning Wild fish and other natural aquatic																
Blue Swimmer Crabs	kg y^{-1}	247.66						247.00	0.66							247.66
Dusky Flathead	kg y^{-1}	664.85						663.47	1.38							664.85
Giant Mud Crab	kg y^{-1}	1,203.20						1,198.36	4.84							1,203.20
Luderick	kg y^{-1}	394.91						392.23	2.68							394.91
Mulloway	kg y^{-1}	555.86						554.23	1.63							555.86
School Prawn	kg y^{-1}	4,869.38						4,852.54	16.84							4,869.38
Sea Mullet	kg y^{-1}	5,031.49						5,015.90	15.59							5,031.49
Yellowfin Bream	kg y^{-1}	592.01						587.73	4.28							592.01
Total biomass	kg y^{-1}	13,559.36						13,511.46	47.90							13,559.36

Table 8.6: Cont.

		Industry			Sector		Marine-Freshwater-Terrestrial			Marine		Marine-Terrestrial		Terrestrial	Freshwater	Total
							MFT1 Brackish tidal			M1 Marine shelf		MT1 Shorelines biome		T7 Intensive land use	F3 Artifical wetlands	
	Units of measure	Agriculture, forestry and fishing	Other industry	Total industry	Households	Government	Supratidal swamp forest	Saltmarsh	Mangroves	Seagrass	Subtitdal sand beds	Muddy shorelines	Sandy shorelines	Other land covers	Constructed lacustirine wetlands	
SUPPLY							MFT1.2*	MFT1.3	MFT1.2	M1.1	M1.7	MT1.2	MT1.3	T7.1	F3.2	
Regulating and maintenance services																
Nursery population and habitat maintenance services	kg ha^{-1} y^{-1}															104
Australian Anchovy	kg y^{-1}										0.09					0.09
Australian Bass	kg y^{-1}										15.13					15.13
Dusky Flathead	kg y^{-1}										185.93					185.93
Eastern King Prawn	kg y^{-1}										0.24					0.24
Flat-tail Mullet	kg y^{-1}										3,476.20					3,476.20
Largehead Hairtail	kg y^{-1}										2.58					2.58
Luderick	kg y^{-1}										362.56					362.56
Sand Whiting	kg y^{-1}										69.90					69.90
Sandy Sprat	kg y^{-1}										8.68					8.68
School Prawn	kg y^{-1}										4,173.10					4,173.10

Table 8.6: Cont.

							Marine-Freshwater-Terrestrial			**Marine**		**Marine-Terrestrial**		**Terrestrial**	**Freshwater**	**Total**
		Industry				**Sector**	**MFT1 Brackish tidal**			**M1 Marine shelf**		**MT1 Shorelines biome**		**T7 Intensive land use**	**F3 Artifical wetlands**	
	Units of measure	Agriculture, forestry and fishing	Other industry	Total industry	Households	Government	Supratidal swamp forest	Saltmarsh	Mangroves	Seagrass	Subtidal sand beds	Muddy shorelines	Sandy shorelines	Other land covers	Constructed lacustrine wetlands	
SUPPLY							MFT1.2*	MFT1.3	MFT1.2	M1.1	M1.7	MT1.2	MT1.3	T7.1	F3.2	
Sea Mullet	kg y^{-1}										14,733.93					14,733.93
Silver Biddy	kg y^{-1}										271.76					271.76
Tailor	kg y^{-1}										48.07					48.07
Tarwhine	kg y^{-1}										450.43					450.43
Yellowfin Bream	kg y^{-1}										7,286.53					7,286.53
Total	kg y^{-1}										31,085.13					31,085.13
Cultural services Recreation-related services																
Recreational fishing	No. of fishing days															499
Bird watching	No. of trips															204

Table 8.7: Ecosystem services supply and use account in physical terms – use table post-restoration. *Continued over page.*

							Marine-Freshwater-Terrestrial			Marine		Marine-Terrestrial		Terrestrial	Freshwater	Total
		Industry				Sector	MFT1 Brackish tidal			M1 Marine shelf		MT1 Shorelines biome		T7 Intensive land use	F3 Artifical wetlands	
	Units of measure	Agriculture, forestry and fishing	Other industry	Total industry	Households	Government	Supratidal swamp forest	Saltmarsh	Mangroves	Seagrass	Subtitdal sand beds	Muddy shorelines	Sandy shorelines	Other land covers	Constructed lacustrine wetlands	
USE							MFT1.2*	MFT1.3	MFT1.2	M1.1	M1.7	MT1.2	MT1.3	T7.1	F3.2	
Provisioning Wild fish and other natural aquatic																
Blue Swimmer Crabs	kg y^{-1}	247.66														247.66
Dusky Flathead	kg y^{-1}	664.85														664.85
Giant Mud Crab	kg y^{-1}	1,203.20														1,203.20
Luderick	kg y^{-1}	394.91														394.91
Mulloway	kg y^{-1}	555.86														555.86
School Prawn	kg y^{-1}	4,869.38														4,869.38
Sea Mullet	kg y^{-1}	5.031.49														5.031.49
Yellowfin Bream	kg y^{-1}	592.01														592.01
Total biomass	kg y^{-1}	13,559.36														13,559.36

Table 8.7: Cont.

							Marine-Freshwater-Terrestrial			Marine		Marine-Terrestrial		Terrestrial	Freshwater	
		Industry				Sector	MFT1 Brackish tidal			M1 Marine shelf		MT1 Shorelines biome		T7 Intensive land use	F3 Artifical wetlands	Total
	Units of measure	Agriculture, forestry and fishing	Other industry	Total industry	Households	Government	Supratidal swamp forest	Saltmarsh	Mangroves	Seagrass	Subtitdal sand beds	Muddy shorelines	Sandy shorelines	Other land covers	Constructed lacustirine wetlands	
USE							MFT1.2*	MFT1.3	MFT1.2	M1.1	M1.7	MT1.2	MT1.3	T7.1	F3.2	
Regulating and maintenance services																
Nursery population and habitat maintenance services	$kg\ ha^{-1}\ y^{-1}$	104														104
Australian Anchovy	$kg\ y^{-1}$										0.09					0.09
Australian Bass	$kg\ y^{-1}$										15.13					15.13
Dusky Flathead	$kg\ y^{-1}$										185.93					185.93
Eastern King Prawn	$kg\ y^{-1}$										0.24					0.24
Flat-tail Mullet	$kg\ y^{-1}$										3,476.20					3,476.20
Largehead Hairtail	$kg\ y^{-1}$										2.58					2.58
Luderick	$kg\ y^{-1}$										362.56					362.56
Sand Whiting	$kg\ y^{-1}$										69.90					69.90
Sandy Sprat	$kg\ y^{-1}$										8.68					8.68
School Prawn	$kg\ y^{-1}$										4,173.10					4,173.10

Table 8.7: Cont.

USE	Units of measure	Agriculture, forestry and fishing	Other industry	Total industry	Households	Government	Supratidal swamp forest	Saltmarsh	Mangroves	Seagrass	Subtidal sand beds	Muddy shorelines	Sandy shorelines	Other land covers	Constructed lacustrine wetlands	Total
		Industry			Sector		Marine-Freshwater-Terrestrial			Marine		Marine-Terrestrial		Terrestrial	Freshwater	
							MFT1 Brackish tidal			M1 Marine shelf		MT1 Shorelines biome		T7 Intensive land use	F3 Artifical wetlands	
							MFT1.2*	MFT1.3	MFT1.2	M1.1	M1.7	MT1.2	MT1.3	T7.1	F3.2	
Sea Mullet	kg y-1										14,733.93					14,733.93
Silver Biddy	kg y-1										271.76					271.76
Tailor	kg y-1										48.07					48.07
Tarwhine	kg y-1										450.43					450.43
Yellowfin Bream	kg y-1										7,286.53					7,286.53
Total	kg y-1										31,085.13					31,085.13
Cultural services Recreation-related services																
Recreational fishing	No. of fishing days															499
Bird watching	No. of trips															204

8.4 Monetary ecosystem service account

Table 8.8: Ecosystem services supply and use account in monetary terms – supply table post-restoration. *Continued over page.*

							Marine-Freshwater-Terrestrial			Marine		Marine-Terrestrial		Terrestrial	Freshwater	Total
		Industry				Sector	MFT1 Brackish tidal			M1 Marine shelf		MT1 Shorelines biome		T7 Intensive land use	F3 Artifical wetlands	
	Units of measure	Agriculture, forestry and fishing	Other industry	Total industry	Households	Government	Supratidal swamp forest	Saltmarsh	Mangroves	Seagrass	Subtidal sand beds	Muddy shorelines	Sandy shorelines	Other land covers	Constructed lacustrine wetlands	
SUPPLY							MFT1.2*	MFT1.3	MFT1.2	M1.1	M1.7	MT1.2	MT1.3	T7.1	F3.2	
Provisioning Wild fish and other natural aquatic																
Blue Swimmer Crabs	AUD y^{-1}							1,262.20	3.39							1,265.59
Dusky Flathead	AUD y^{-1}							3,270.72	6.78							3,277.50
Giant Mud Crab	AUD y^{-1}							16,845.43	67.94							16,913.37
Luderick	AUD y^{-1}							407.52	2.79							410.31
Mulloway	AUD y^{-1}							2,960.28	8.69							2,698.97
School Prawn	AUD y^{-1}							23,998.53	83.27							24,081.80
Sea Mullet	AUD y^{-1}							8,984.48	27.94							9,012.42
Yellowfin Bream	AUD y^{-1}							3,735.30	27.23							3,762.53
Total biomass	AUD y^{-1}							61,464.46	228.03							61,692.49

Table 8.8: Cont.

							Marine-Freshwater-Terrestrial			Marine		Marine-Terrestrial		Terrestrial	Freshwater	Total
		Industry			Sector		MFT1 Brackish tidal			M1 Marine shelf		MT1 Shorelines biome		T7 Intensive land use	F3 Artifical wetlands	
	Units of measure	Agriculture, forestry and fishing	Other industry	Total industry	Households	Government	Supratidal swamp forest	Saltmarsh	Mangroves	Seagrass	Subtitdal sand beds	Muddy shorelines	Sandy shorelines	Other land covers	Constructed lacustirine wetlands	
SUPPLY							MFT1.2*	MFT1.3	MFT1.2	M1.1	M1.7	MT1.2	MT1.3	T7.1	F3.2	
Regulating and maintenance services																
Nursery population and habitat maintenance services																
Australian Anchovy	AUD y^{-1}										0					0
Australian Bass	AUD y^{-1}										0					0
Dusky Flathead	AUD y^{-1}										0					0
Eastern King Prawn	AUD y^{-1}										0					0
Flat-tail Mullet	AUD y^{-1}										0					0
Largehead Hairtail	AUD y^{-1}										0					0
Luderick	AUD y^{-1}										0					0
Sand Whiting	AUD y^{-1}										0					0
Sandy Sprat	AUD y^{-1}										0					0
School Prawn	AUD y^{-1}										0					0

Table 8.8: Cont.

							Marine-Freshwater-Terrestrial			**Marine**		**Marine-Terrestrial**		**Terrestrial**	**Freshwater**	**Total**
		Industry			**Sector**		**MFT1 Brackish tidal**			**M1 Marine shelf**		**MT1 Shorelines biome**		**T7 Intensive land use**	**F3 Artifical wetlands**	
	Units of measure	Agriculture, forestry and fishing	Other industry	Total industry	Households	Government	Supratidal swamp forest	Saltmarsh	Mangroves	Seagrass	Subtidal sand beds	Muddy shorelines	Sandy shorelines	Other land covers	Constructed lacustrine wetlands	
SUPPLY							MFT1.2*	MFT1.3	MFT1.2	M1.1	M1.7	MT1.2	MT1.3	T7.1	F3.2	
Sea Mullet	AUD y^{-1}										0					0
Silver Biddy	AUD y^{-1}										0					0
Tailor	AUD y^{-1}										0					0
Tarwhine	AUD y^{-1}										0					0
Yellowfin Bream	AUD y^{-1}										0					0
Total											0					0
Cultural services Recreation-related services																
Recreational fishing	AUD$				93,298											93,298
Bird watching	AUD$				35,641											35,641

Table 8.9: Ecosystem services use account in monetary terms – use table post-restoration. *Continued over page.*

USE	Units of measure	Industry: Agriculture, forestry and fishing	Industry: Other industry	Industry: Total industry	Sector: Households	Sector: Government	Marine-Freshwater-Terrestrial, MFT1 Brackish tidal: Supratidal swamp forest	Marine-Freshwater-Terrestrial, MFT1 Brackish tidal: Saltmarsh	Marine-Freshwater-Terrestrial, MFT1 Brackish tidal: Mangroves	Marine, M1 Marine shelf: Seagrass	Marine, M1 Marine shelf: Subtitdal sand beds	Marine-Terrestrial, MT1 Shorelines biome: Muddy shorelines	Marine-Terrestrial, MT1 Shorelines biome: Sandy shorelines	Terrestrial, T7 Intensive land use: Other land covers	Freshwater, F3 Artifical wetlands: Constructed lacustirine wetlands	Total
							MFT1.2*	MFT1.3	MFT1.2	M1.1	M1.7	MT1.2	MT1.3	T7.1	F3.2	
Provisioning Wild fish and other natural aquatic																
Blue Swimmer Crabs	AUD$	1,265.59														1,265.59
Dusky Flathead	AUD$	3,277.50														3,277.50
Giant Mud Crab	AUD$	16,913.37														16,913.37
Luderick	AUD$	410.31														410.31
Mulloway	AUD$	2,698.97														2,698.97
School Prawn	AUD$	24,081.80														24,081.80
Sea Mullet	AUD$	9,012.42														9,012.42
Yellowfin Bream	AUD$	3,762.53														3,762.53
Total biomass	AUD$	61,692.49														61,692.49

Table 8.9: Cont.

							Marine-Freshwater-Terrestrial			Marine		Marine-Terrestrial		Terrestrial	Freshwater	
		Industry			Sector		MFT1 Brackish tidal			M1 Marine shelf		MT1 Shorelines biome		T7 Intensive land use	F3 Artifical wetlands	
	Units of measure	Agriculture, forestry and fishing	Other industry	Total industry	Households	Government	Supratidal swamp forest	Saltmarsh	Mangroves	Seagrass	Subtitdal sand beds	Muddy shorelines	Sandy shorelines	Other land covers	Constructed lacustirine wetlands	Total
USE							MFT1.2*	MFT1.3	MFT1.2	M1.1	M1.7	MT1.2	MT1.3	T7.1	F3.2	
Regulating and maintenance services																
Nursery population and habitat maintenance services	AUD$															
Australian Anchovy	AUD y-1										0					0
Australian Bass	AUD y-1										0					0
Dusky Flathead	AUD y-1										0					0
Eastern King Prawn	AUD y-1										0					0
Flat-tail Mullet	AUD y-1										0					0
Largehead Hairtail	AUD y-1										0					0
Luderick	AUD y-1										0					0
Sand Whiting	AUD y-1										0					0
Sandy Sprat	AUD y-1										0					0
School Prawn	AUD y-1										0					0

Table 8.9: Cont.

							Marine-Freshwater-Terrestrial			**Marine**		**Marine-Terrestrial**		**Terrestrial**	**Freshwater**	
		Industry				**Sector**	**MFT1 Brackish tidal**			**M1 Marine shelf**		**MT1 Shorelines biome**		**T7 Intensive land use**	**F3 Artifical wetlands**	**Total**
	Units of measure	Agriculture, forestry and fishing	Other industry	Total industry	Households	Government	Supratidal swamp forest	Saltmarsh	Mangroves	Seagrass	Subtidal sand beds	Muddy shorelines	Sandy shorelines	Other land covers	Constructed lacustirine wetlands	
USE							MFT1.2*	MFT1.3	MFT1.2	M1.1	M1.7	MT1.2	MT1.3	T7.1	F3.2	
Sea Mullet	AUD y^{-1}										0					0
Silver Biddy	AUD y^{-1}										0					0
Tailor	AUD y^{-1}										0					0
Tarwhine	AUD y^{-1}										0					0
Yellowfin Bream	AUD y^{-1}										0					0
Total																
Cultural services Recreation-related services																
Recreational fishing	AUD$				93,298											93,298
Bird watching	AUD$				35,641											35,641

8.5 Regulation and maintenance

Table 8.10: Carbon asset account table.

Realm	**Marine-Freshwater-Terrestrial**			**Marine**		**Marine-Terrestrial**		**Terrestrial**	**Freshwater**	
Biome	**MFT1 Brackish tidal**			**M1 Marine shelf**		**MT1 Shorelines biome**		**T7 Intensive land use**	**F3 Artifical wetlands**	
Selected Ecosystem Functional Group (EFG)	Supratidal swamp forest MFT1.2* tonnes C	Saltmarsh MFT1.3 tonnes C	Mangroves MFT1.2 tonnes C	Seagrass MFT1.1 tonnes C	Subtidal sand beds MFT1.7 tonnes C	Muddy shorelines MFT1.2 tonnes C	Sandy shorelines MFT1.3 tonnes C	Other land covers T7.1 tonnes C	Constructed lacustrine wetlands F3.2 tonnes C	**Total ecosystem extent** tonnes C
Opening extent 2006 (pre-restoration)	***41,929***	-	-	-	-	-	0	236,651	**0**	**278,580**
Additions										
Managed expansion										
Unmanaged expansion										
Total additions										
Reductions										
Managed reduction										
Unmanaged reduction										
Total reductions										
Net change										
Closing extent	***98,698***	***136,449***	**-**	**-**	**-**	**-**	***0***	***59,206***	***0***	***294,353***

Table 8.11: Climate regulation supply and use account in physical terms – post-restoration.

							Marine-Freshwater-Terrestrial			Marine		Marine-Terrestrial		Terrestrial	Freshwater	Total
		Industry				Sector	MFT1 Brackish tidal			M1 Marine shelf		MT1 Shorelines biome		T7 Intensive land use	F3 Artifical wetlands	
	Units of measure	Agriculture, forestry and fishing	Other industry	Total industry	Households	Government	Supratidal swamp forest	Saltmarsh	Mangroves	Seagrass	Subtitdal sand beds	Muddy shorelines	Sandy shorelines	Other land covers	Constructed lacustirine wetlands	
SUPPLY							MFT1.2*	MFT1.3	MFT1.2	M1.1	M1.7	MT1.2	MT1.3	T7.1	F3.2	
Regulating and maintenance *Global climate regulation services*																
Sequestration	tonnes $CO_2e\ yr^{-1}$						1,203	1,204						0		2,407
Storage	tonnes CO_2e						98,698	136,449						59,206		294,353
USE																
Regulating and maintenance *Global climate regulation services*																
Sequestration	tonnes $CO_2e\ yr^{-1}$					*2,407*										*2,407*
Storage	tonnes CO_2e					294,353										294,353

Table 8.12: Flood Mitigation supply and use account in physical terms – supply and use table, post-restoration.

							Marine-Freshwater-Terrestrial			Marine		Marine-Terrestrial		Terrestrial	Freshwater	Total
		Industry			Sector		MFT1 Brackish tidal			M1 Marine shelf		MT1 Shorelines biome		T7 Intensive land use	F3 Artifical wetlands	
	Units of measure	Agriculture, forestry and fishing	Other industry	Total industry	Households	Government	Supratidal swamp forest	Saltmarsh	Mangroves	Seagrass	Subtitdal sand beds	Muddy shorelines	Sandy shorelines	Other land covers	Constructed lacustirine wetlands	
SUPPLY							MFT1.2*	MFT1.3	MFT1.2	M1.1	M1.7	MT1.2	MT1.3	T7.1	F3.2	
Ecosystem services																
Flood mitigation	Number of properties protected															
USE																
Ecosystem services																
Flood mitigation	Number of properties protected															

Table 8.13: Flood Mitigation supply and use account in monetary terms – supply and use table, post-restoration.

							Marine-Freshwater-Terrestrial			Marine		Marine-Terrestrial		Terrestrial	Freshwater	Total
		Industry			Sector		MFT1 Brackish tidal			M1 Marine shelf		MT1 Shorelines biome		T7 Intensive land use	F3 Artifical wetlands	
	Units of measure	Agriculture, forestry and fishing	Other industry	Total industry	Households	Government	Supratidal swamp forest	Saltmarsh	Mangroves	Seagrass	Subtidal sand beds	Muddy shorelines	Sandy shorelines	Other land covers	Constructed lacustirine wetlands	
SUPPLY							MFT1.2*	MFT1.3	MFT1.2	M1.1	M1.7	MT1.2	MT1.3	T7.1	F3.2	
Ecosystem services																
Flood mitigation	AUD$															
USE																
Ecosystem services																
Flood mitigation	AUD$															

9. Appendices

Appendix A1. Data enquiry from Key Informants (Recreational fishing)

We were aiming to gather information on: (a) fishing activities and fishers in the restoration site (e.g. annual report/survey or observational/judgemental/anecdotal evidence) (plus number of trips, duration of recreation, travel origin) before and after restoration; or (b) data on recreational fishing and fishers in adjacent areas (which can be directly linked to the restoration activity), (c) data related to recreational activities (e.g. preferred locations, seasonality of fishing, multi-site recreation). In particular, our data enquiry is framed using the following list of questions:

1. Did people recreationally fish at the site, or adjacent areas prior to restoration (and if so, how many per annum)?
2. How many people have been fishing at the site, or adjacent areas in a recent 12-month period (e.g. 2021 or 2022)?
3. Has there been an increase in fish numbers, biomass, or species present (relevant to the recreational fishery) since pre-restoration (2006/7) to now (~2021/22)? Did any increase in fishing activity begin immediately after restoration began, or grow over time?
4. If there has been an increase in recreational fishing activity in adjacent areas since restoration, is there clear link/evidence that this is driven by the restoration site (i.e. from producing more fish that travel to the adjacent areas to be caught)?
5. Were there particular sites preferred for rec fishing in the general area prior to restoration? Are the same sites still preferred? Are there new sites also preferred now?
6. Is there particular season for observing fishing activities and seasonal variation of visit frequencies of recreational fishing by anglers or residents? (We would also appreciate getting any information regarding the travel of recreation fishers – local, regional, national, tourist)
7. Do fishers typically visit only the Tomago site when going on a fishing trip, or do they usually make multiple stops at different fishing sites?

Appendix A2. Data enquiry from Key Informants (Birdwatching)

We were aiming to identify whether there has been (a) an increase in the amount of birdwatching occurring at the restoration site and data sets/reports that exist recording the number of bird observers that visit the site or surrounding areas (or in lieu of that through observation/ judgement/ anecdotal evidence provided by managers and/or coordinators of the bird watching club); (b) if there has been an increase in birdwatching occurring in nearby areas that can be attributed to the environmental improvements made at the restoration site. The Key Informants were requested to provide us some information to the following questions (or point us to another contact):

1. Are there any new bird species; and an increase in the number of birds using the Tomago site since start of restoration (2006/7) to now (~2021/22)?
2. Did any bird observers visit Tomago before the restoration project i.e. 2006/7 (and if so, how many)?
3. How many bird observers visited Tomago in a recent 12-month period (e.g. 2021 or 2022)?
4. Has the number of bird observers in the general area (e.g. including nearby wetlands) increased over the last ~15 years? And if so, is this increase linked to the restoration of Tomago (which has improved the quality of saltmarsh)?
5. Were there particular sites preferred for bird observing in the general area prior to restoration? Are the same sites still preferred? Are there new sites also preferred now?
6. Is there a particular season for birdwatching activities (e.g. linked to migratory birds) and data showing seasonal variation in the number of bird observers?
7. Do bird observers typically visit only the Tomago site when going on a bird watching trip, or do they usually make multiple stops at different fishing sites?

Appendix B

As an alternative to the use of exchange values valuation studies based on welfare estimates can be used for BT to the economic valuation of recreational fishing and birdwatching in coastal wetland ecosystems in Australia (based on systematic literature review).

Table B.1: List of identified recreational services valuation studies of Australian coastal and marine wetland ecosystems based on welfare estimates. *Continued over page.*

Study ID	Study Author	Year valued	Habitat	Region/location	What is valued	Valuation method	Value measurement	Estimate (AUD)	Remark
1	Pascoe et al., 2014[227]	2013	Multipurpose coastline	Moreton Bay Marine Park, Queensland	Recreational fishing	TC	per trip/angler	58.23-60.58	Using "marginal cost only" (lower and higher trip assumption)
1	Pascoe et al., 2014	2013	Multipurpose coastline	Moreton Bay Marine Park, Queensland	Recreational fishing	TC	per trip/angler	105-108	Using "Total cost" (lower and higher trip assumption)
1	Pascoe et al., 2014	2013	Multipurpose coastline	Moreton Bay Marine Park, Queensland	Recreational fishing	TC	per trip/group	128.91-134.1	Using "marginal cost only" (lower and higher trip assumption)
1	Pascoe et al., 2014	2013	Mutipurpose coastline	Moreton Bay Marine Park, Queensland	Recreational fishing	TC	per trip/group	232.68-239.15	Using "Total cost" (lower and higher trip assumption)
2	Windle et al., 2017[228]	2016	Harbour area, beaches	Gladstone Harbour, Queensland, Australia	Recreational fishing	TC	per trip/person	143	
3	Huang et al., 2020[229]	2016	Seagrass	Port Phillip Bay, Victoria	Recreational fishing	CM	per trip/angler	0.39-1.22	Welfare gains from seagrass rehabilitation (10 and 30%)

[227] Opening account year = 2005, closing account year = 2021). Values are mean of all cells in restoration activity boundary, values brackets indicate standard deviation. Comparison area for opening and closing mean values is the mutually inclusive area of the ecosystem type (i.e. where mangrove was present in both pre- and post-restoration activities). *unreliable estimates from datasets and not included.

[228] Windle, J., Rolfe, J., & Pascoe, S. (2017). Assessing recreational benefits as an economic indicator for an industrial harbour report card. Ecological Indicators, 80, 224-231. https://doi.org/10.1016/j.ecolind.2017.05.036

[229] Huang, B., Young, M. A., Carnell, P. E., Conron, S., Ierodiaconou, D., Macreadie, P. I., & Nicholson, E. (2020). Quantifying welfare gains of coastal and estuarine ecosystem rehabilitation for recreational fisheries. Science of The Total Environment, 710, 134680. https://doi.org/10.1016/j.scitotenv.2019.134680

Table B.1: Cont.

Study ID	Study Author	Year valued	Habitat	Region/location	What is valued	Valuation method	Value measurement	Estimate (AUD)	Remark
3	Huang et al., 2020	2016	Seagrass	Port Phillip Bay, Victoria	Recreational fishing	CM	per trip/angler	2.27-7.35	Welfare gains for 10 and 30% increase in seagrass cover
3	Huang et al., 2020	2016	Seagrass	Western Port, Victoria	Recreational fishing	CM	per trip/angler	5.49-19.57	Welfare gains from seagrass rehabilitation (10 and 30%)
3	Huang et al., 2020	2016	Seagrass	Western Port, Victoria	Recreational fishing	CM	per trip/angler	19.18-85.55	Welfare gains from (10 and 30%) increase in seagrass cover
4	Prayaga et al., 2010[230]	2010	Coastal beaches	Capricorn Coast, Queensland	Recreational fishing	TC	per trip/angler	167	
5	Farr and Stoeckl, 2018[231]	2012	GBR coast catchment	GBR World Heritage, Queensland	Recreational fishing	TC	per trip/angler	441	
6	Rolfe and Dyack, 2021[232]	2021	GBR	GBR, Queensland	Recreational fishing	TC	per trip/angler	295	
7	Rolfe et al., 2011[233]	2011	GBR	GBR Marine Park, Queensland	Recreational fishing, boating and sailing	TC	per trip/angler	183	
8	Kandulu et al., 2021[234]	2021	Saltwaters	Different regions and subregions, Queensland	Recreational fishing	TC	per trip/angler	183	

230 Prayaga, P., Rolfe, J., & Stoeckl, N. (2010). The value of recreational fishing in the Great Barrier Reef, Australia: A pooled revealed preference and contingent behaviour model. Marine Policy, 34(2), 244-251. https://doi.org/10.1016/j.marpol.2009.07.002

231 Farr, M., & Stoeckl, N. (2018). Overoptimism and the undervaluation of ecosystem services: A case-study of recreational fishing in Townsville, adjacent to the Great Barrier Reef. Ecosystem Services, 31, 433-444. https://doi.org/10.1016/j.ecoser.2018.02.010

232 Rolfe, J., & De Valck, J. (2021). Values for protecting the Great Barrier Reef: A review and synthesis of studies over the past 35 years. Marine Pollution Bulletin, 169, 112531.

233 Rolfe, J., Gregg, D., & Tucker, G. (2011). Valuing local recreation in the Great Barrier Reef, Australia (Environmental Economics Research Hub Research Report 102. Canberra:, Issue

234 Kandulu, J., Bailey, H., & Magnusson, A., BDO. (2021). Economic contribution of recreational fishing by Queenslanders to Queensland: A Report for Fisheries Queensland. Fisheries Queensland

Table B.1: Cont.

Study ID	Study Author	Year valued	Habitat	Region/location	What is valued	Valuation method	Value measurement	Estimate (AUD)	Remark
8	Kandulu et al., 2021	2021	Saltwaters	Different regions and subregions, Queensland	Recreational fishing	TC	per trip/angler	56-76	
9	McLeod and Lindner, 2018[235]	2018	Saltwaters	Western Australia	Recreational fishing	BT	per day/angler	178	
10	Carnell et al., 2019[236]	2019	Mangroves and Saltmarsh	Port Phillip, Victoria	Recreational fishing	CM	per trip/angler	13	
10	Carnell et al., 2019	2019	Mangroves and Saltmarsh	Western Port, Victoria	Recreational fishing	CM	per trip/angler	85	
11	Pascoe, 2019[237]	2017	Coastal beach	Sydney, NSW	Recreational fishing	TC	per trip/angler	23.75	Recreational fishing as one of the of travel activities
12	Steven et al., 2017[238]	2016	Multiple birding sites	Conservation sites, Australia	Birdwatching	CM	per trip/person	105-135	Amount of bird diversity (medium 20-60 species and high >60 species) by quantity driven birders

[235] McLeod, P., & Lindner, R. (2018). Economic dimension of recreational fishing in Western Australia: Research report for the recreational fishing initiatives fund. Department of Primary Industries and Regional Government and Recfish west.

[236] Carnell, P. E., Reeves, S. E., Nicholson, E., Macreadie, P., Ierodiaconou, D., Young, M., Kelvin, J., Janes, H., Navarro, A., Fitzsimons, J., & Gillies, C. L. (2019). Mapping Ocean Wealth Australia: The value of coastal wetlands to people and nature. The Nature Conservancy, Melbourne.

[237] Pascoe, S. (2019). Recreational beach use values with multiple activities. Ecological Economics, 160, 137–144.

[238] Steven, R., Smart, J. C. R., Morrison, C., & Castley, J. G. (2017). Using a choice experiment and birder preferences to guide bird-conservation funding. Conservation Biology, 31(4), 818-827. https://doi.org/10.1111/cobi.12849

Table B.1: Cont.

Study ID	Study Author	Year valued	Habitat	Region/location	What is valued	Valuation method	Value measurement	Estimate (AUD)	Remark
12	Steven et al., 2017	2016	Multiple birding sites	Conservation sites, Australia	Birdwatching	CM	per trip/person	18-36	Amount of bird diversity (medium 20-60 species and high >60 species) by special birders
12	Steven et al., 2017	2016	Multiple birding sites	Conservation sites, Australia	Birdwatching	CM	per trip/person	31-45	Number of threatened spp (medium, 1-3 and high, >3) by special birders
12	Steven et al., 2017	2016	Multiple birding sites	Conservation sites, Australia	Birdwatching	CM	per trip/person	18-66	Number of endemic spp (medium, 1-6; high >6 species)

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