Blue carbon opportunities at a local scale

Western Port Bay & eastern Port Phillip Bay

Blue Carbon Lab

DEAKIN UNIVERSITY

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About Deakin's Blue Carbon Lab

Deakin University's Blue Carbon Lab offers innovative research solutions for helping to mitigate climate change and improve natural capital, while also contributing to jobs, economic growth, capacity building and community wellbeing.

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Acknowledgment

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South East Councils Climate Change Alliance

Cardinia

City of Casey

Frankston City

Bayside City Council

City of Kingston

BASS COAST

MORNINGTON PENINSULA Shire

Deakin University acknowledges Aboriginal people as Australia’s first people, and the Bunurong peoples of the South-Eastern Kulin Nation as the Traditional Owners and custodians of the land and sea where this research focused.

We pay respect to all Aboriginal community Elders, past and present, whose knowledge and relationships to Sea Country are fundamental to the health of the coastal environment and the success of any strategy to protect and rehabilitate blue carbon ecosystems.

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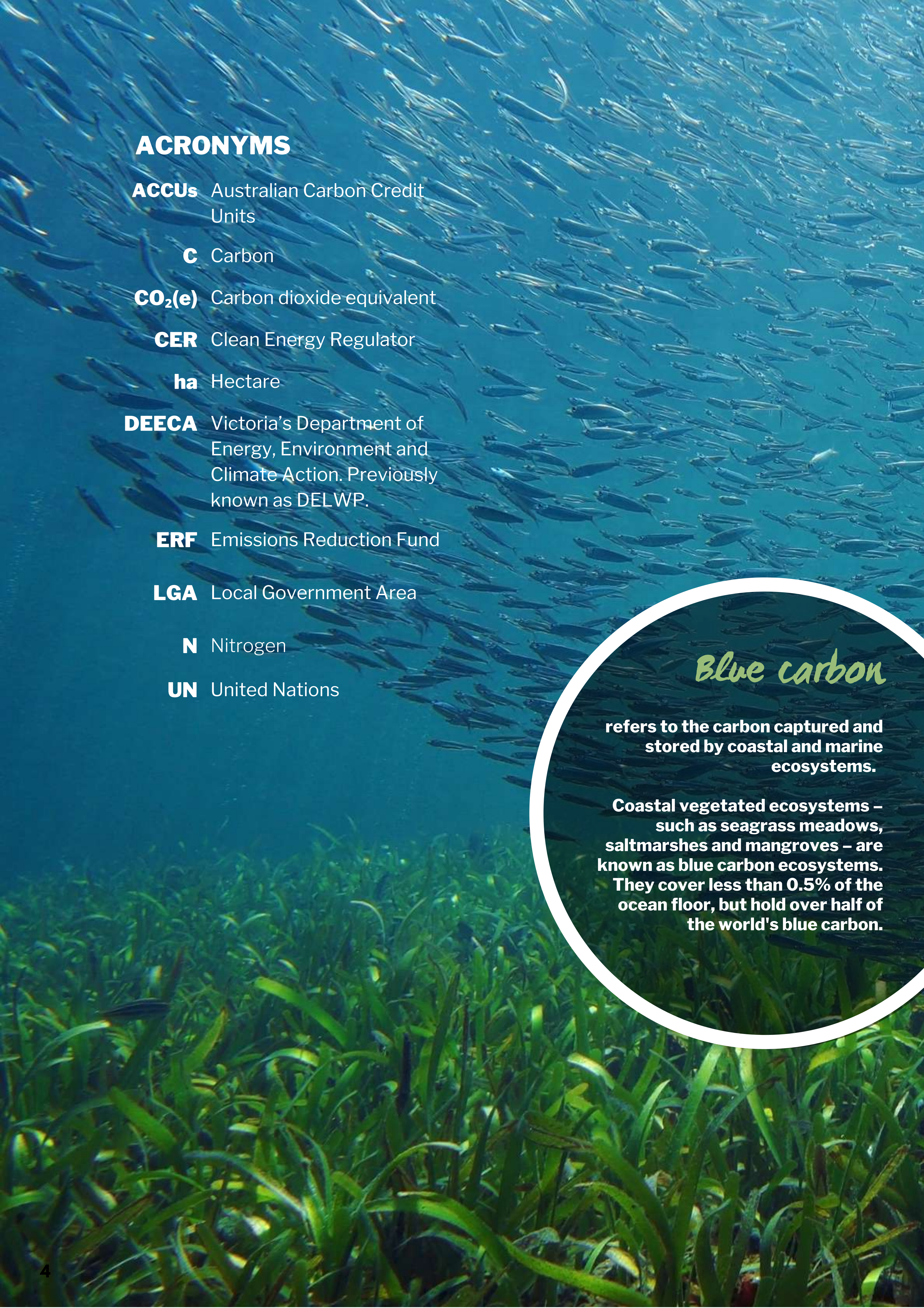


ACRONYMS

ACCUs	Australian Carbon Credit Units
C	Carbon
CO_2(e)	Carbon dioxide equivalent
CER	Clean Energy Regulator
ha	Hectare
DEECA	Victoria's Department of Energy, Environment and Climate Action. Previously known as DELWP.
ERF	Emissions Reduction Fund
LGA	Local Government Area
N	Nitrogen
UN	United Nations

Blue carbon

refers to the carbon captured and stored by coastal and marine ecosystems.

Coastal vegetated ecosystems – such as seagrass meadows, saltmarshes and mangroves – are known as blue carbon ecosystems. They cover less than 0.5% of the ocean floor, but hold over half of the world's blue carbon.

Executive Summary

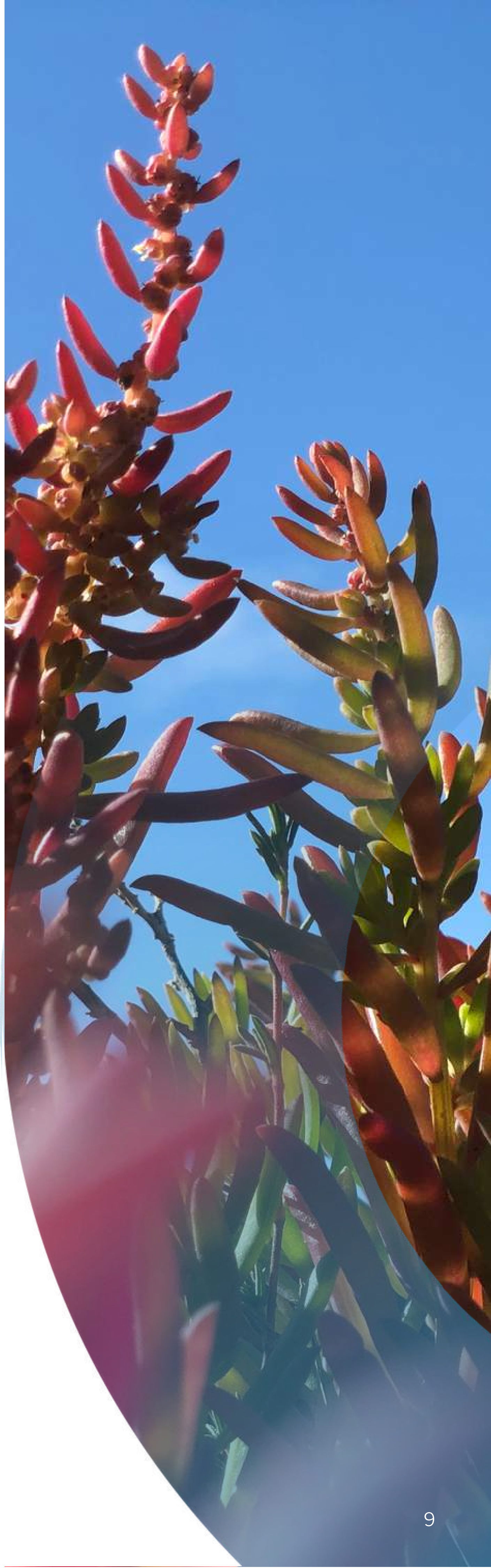
Western Port Bay and eastern Port Phillip Bay hold 24% of Victoria's coastal blue carbon ecosystems (~19,600 ha) which provide a wide range of ecosystem services for climate change mitigation and adaptation.

Current mangroves, saltmarshes and seagrasses in the region store ~31.5% of the state's blue carbon (> 2 million tonnes C or 8.9 million tonnes CO_2e) and offer a wide range of ecosystem services including carbon sequestration (>12,000 tonnes C yr^{-1}), nitrogen fixation (>400 tonnes N yr^{-1}), fisheries enhancement (>60 million Kg fish yr^{-1}) and coastal protection (>45,000 properties located within 1 km of coastal wetlands).

According to the best available historical maps, saltmarsh and mangrove habitat has declined by ~16% and 5%, respectively (since European settlement), while seagrass distribution has increased by ~40%. However, due to the natural spatial and temporal fluctuations (seasonal-interannual) of seagrass distribution, it is complex to fully understand the gains and losses through time.

Our analysis indicates there is scope to undertake blue carbon restoration in the region. For example, more than 800 ha of historical mangrove forests and saltmarshes could be restored through tidal reinstatement (441 ha) and fencing (321 ha), with an additional 9,000+ ha potentially available from managing future sea-level rise inundation that leads to increased saltmarsh and mangrove cover. Further opportunities could exist from seagrass restoration, however, these were not estimated in this study (read limitations below).

The management of sea-level rise (by allowing accommodating space for the retreat of coastal wetlands) is the restoration action that could lead to the highest blue carbon opportunities throughout the region, highlighting the need for



councils to plan and account for future sea-level conditions. By 2040, even with early signs of predicted sea-level rise, the carbon sequestration from restored mangroves would be on average 91 tonnes C yr^{-1} (equivalent to 334 tonnes CO_2e yr^{-1}), while for saltmarshes ~17,900 tonnes C yr^{-1} (equivalent to 65,700 tonnes CO_2e yr^{-1}). The opportunities are likely to increase with later signs of sea-level rise by 2070 and 2100.

In contrast, tidal reinstatement (which is included as a blue carbon method under the Emissions Reduction Fund) in the region would lead to a carbon drawdown of ~874 tonnes C yr^{-1} (equivalent to about 3,208 tonnes CO_2e yr^{-1}). Restoration via tidal reinstatement would also provide other ecosystem services, such as fixating ~50 tonnes N yr^{-1}, generating >28,000 kg fish yr^{-1} and protecting >600 properties located within 1 km of the restored blue carbon ecosystems.

Fencing is a promising low-cost management option to restore coastal wetlands, which is already being implemented across Victoria. Our analysis identified 321 ha amenable for restoration through fencing, which could lead to ~638 tonnes C yr^{-1} (equivalent to ~2,341 tonnes CO_2e yr^{-1}). In addition, fencing could potentially lead to the fixation of 37 tonnes N yr^{-1}, the generation of ~21,000 kg fish yr^{-1}, and the protection of ~581 properties located within 1 km of the restored wetlands.

High-resolution maps and data for each council are available in the Information Sheets included in this report.

The restoration opportunities identified through this project are conservative given that we only considered the three most scalable restoration actions for Australia and we did not quantify seagrass restoration opportunities. Large uncertainties related to the restoration of seagrass in Victoria (e.g., what are the main local drivers of degradation, how to effectively cease them, what are the most cost-effective methods for local restoration, how to improve seagrass survival rate), along with the lack of information on additionality opportunities, limit our current capacity to estimate the return on investment from management actions to restore this complex ecosystem (Roadmap Action 1.4).

We developed a 'Blue carbon roadmap' that highlights a long-term path geared towards advancing blue carbon opportunities in the region. The Roadmap proposes a series of activities to advance blue carbon research, engage communities, improve governance, and kick-start blue carbon conservation and restoration projects in the region. The implementation of this Roadmap will be critical to address the limitations of this project and implement blue carbon projects at the site level.

Introduction

Introduction

Climate change requires ambitious commitments at different levels (i.e., international, national, regional) to reduce global average temperature to below 1.5°C above pre-industrial levels (Hulme 2016). However, achieving this target and reaching Net Zero requires more than just reducing emissions. To account for processes that will be exceptionally difficult to decarbonise completely, we must also remove greenhouse gases from the atmosphere, thereby balancing out at 'net' zero (Smith et al. 2016, Hulme 2016).

In this case, coastal wetlands such as mangrove forests, seagrass meadows, and saltmarshes are increasingly recognised as an effective natural climate solution (Macreadie et al. 2021). These ecosystems are capable of drawing atmospheric carbon back into the soil while simultaneously helping communities adapt to the impacts of climate change by enhancing coastal resilience, biodiversity, and local livelihoods (Mcleod et al. 2011, Duarte et al. 2013, Himes-Cornell et al. 2018, Friess et al. 2020, Unsworth et al. 2022).

Coastal wetlands, *also known as blue carbon ecosystems*, can sequester carbon up to 40 times faster than any terrestrial ecosystem and lock it into the soil for millennial time scales (Mcleod et al. 2011, Duarte et al. 2013, Macreadie et al. 2021). Their high productivity, along with a strategic location in the land-sea interface, allows them to accumulate important amounts of sediment and carbon in the soil. Then, the anaerobic water-logged conditions of the environment limit carbon decomposition and secure its long-term permanence (Mcleod et al. 2011, Duarte et al. 2013).

Unfortunately, when d*egraded*, coastal wetlands stop capturing carbon and can become important sources of greenhouse gases (GHG). Physical, biological and chemical disturbances can trigger the release of ancient soil carbon stored back into the atmosphere (in the form of methane and carbon dioxide; Mcleod et al. 2011, Pendleton et al. 2012).

Additional to their carbon mitigation capacity, coastal wetlands provide an extensive array of ecosystem services that can help local communities adapt to climate change (Himes-Cornell et al. 2018, Friess et al. 2020, Unsworth et al. 2022).

- **Enhancing fisheries and wildlife biodiversity (including threatened and endangered species) from habitat and food provisioning.**
- **Increasing coastal resilience to storm surges and sea-level rise by stabilising shoreline soils and serving as green walls.**
- **Improving water quality by removing and retaining excess nutrients, sediments, and pollutants.**
- **Supporting local economies and coastal livelihoods from fisheries and eco-tourism activities.**
- **Providing for coastal recreation and enabling communities to connect with nature.**
- **Underpinning Indigenous history and providing cultural services and spiritual beliefs**

For example, their robust root system and vegetative structure enhance coastal resilience against extreme storms and sea-level rise by preventing soil erosion and acting as a green barrier (Arkema et al. 2013, Temmerman et al. 2013). Further, coastal wetlands provide habitat, nursery grounds and food to hundreds of fishes, birds, and invertebrate species (Duffy 2006, Carugati et al. 2018, Unsworth et al. 2019, Jänes et al. 2020a, 2020b, Jinks et al. 2020). Coastal wetlands thereby help maintain critical biodiversity (including reducing extinction risk) and support local livelihoods from fishery resources and eco-tourism opportunities.

Australia is the wealthiest country in carbon sequestration, generating an annual net benefit of US$22.8 billion (Bertram et al. 2021), while also storing 5-11% of the world's blue carbon (Serrano et al. 2019). In Australia, the State of Victoria is home to approximately 80,000 hectares of coastal wetlands (Costa et al. 2022b), which, according to recent studies, can store ~20-40 Tg C in the top meter of the sediment (Serrano et al. 2019, Young et al. 2021). Furthermore, Victoria has been at the forefront of blue carbon research in Australia with a recent state-wide study finding that ecosystem services provided by coastal wetlands are estimated at AUD 120.9 billion per year (Costa et al. 2022b). Other recent studies focused on: estimating and valuing ecosystem services generated by coastal wetlands (Carnell et al. 2019, Huang et al. 2020, Jänes et al. 2020a, 2020b); identifying restoration opportunities (Gulliver et al. 2020, Moritsch et al. 2021); estimating blue carbon stocks and their sequestration potential (Ewers Lewis et al. 2018, 2020, Carnell et al. 2022a); and assessing the costs and benefits from different management actions (Carnell et al. 2022b, Costa et al. 2022b).

However, since most of these studies were at larger scales, we still need to understand the blue carbon distribution and potential additionality opportunities at regional and local (council level) scales. In this sense, this study explored the blue carbon ecosystems and the additionality opportunities in Western Port Bay and eastern Port Phillip Bay by focusing on four components:

- estimating the distribution extent of existing coastal wetlands;
- quantifying restoration opportunities;
- estimating ecosystems services; and
- developing a strategic roadmap to advance blue carbon opportunities in the region.

Altogether, this report provides spatial data and local knowledge to further blue carbon science and projects in the region. Furthermore, to facilitate decision-making at a local scale, individual factsheets are provided for each of the seven councils (City of Bayside, City of Kingston, City of Frankston, Mornington Peninsula Shire, City of Casey, Cardinia Shire, and Bass Coast Shire) and French Island.

Methods

Methods

Victoria's coastline holds over ~80,000 ha of blue carbon ecosystems including mangrove forests, seagrass beds and saltmarshes (Costa et al. 2022b).

This project specifically examines the distribution of these three blue carbon ecosystems throughout seven Local Government Areas (LGAs) across Western Port Bay and eastern Port Phillip Bay (City of Bayside, City of Kingston, City of Frankston, Mornington Peninsula Shire, City of Casey, Cardinia Shire, and Bass Coast Shire), including French Island (Figure 1).

Located within the study region, the Western Port Biosphere Reserve has a combined area of approximately 214,200 ha, including five LGAs and French Island. The Biosphere is endowed with an important area of coastal blue carbon ecosystems that serve as critical habitat for migratory birds and is listed under the Ramsar Convention.

Evaluating the past and current distribution of blue carbon ecosystems

We used the mapped pre-European and current distribution (Boon et al. 2011) of saltmarshes and mangroves in Victoria to estimate the area of blue carbon ecosystems within the study area. Unfortunately, there is only sparse spatial information available on the

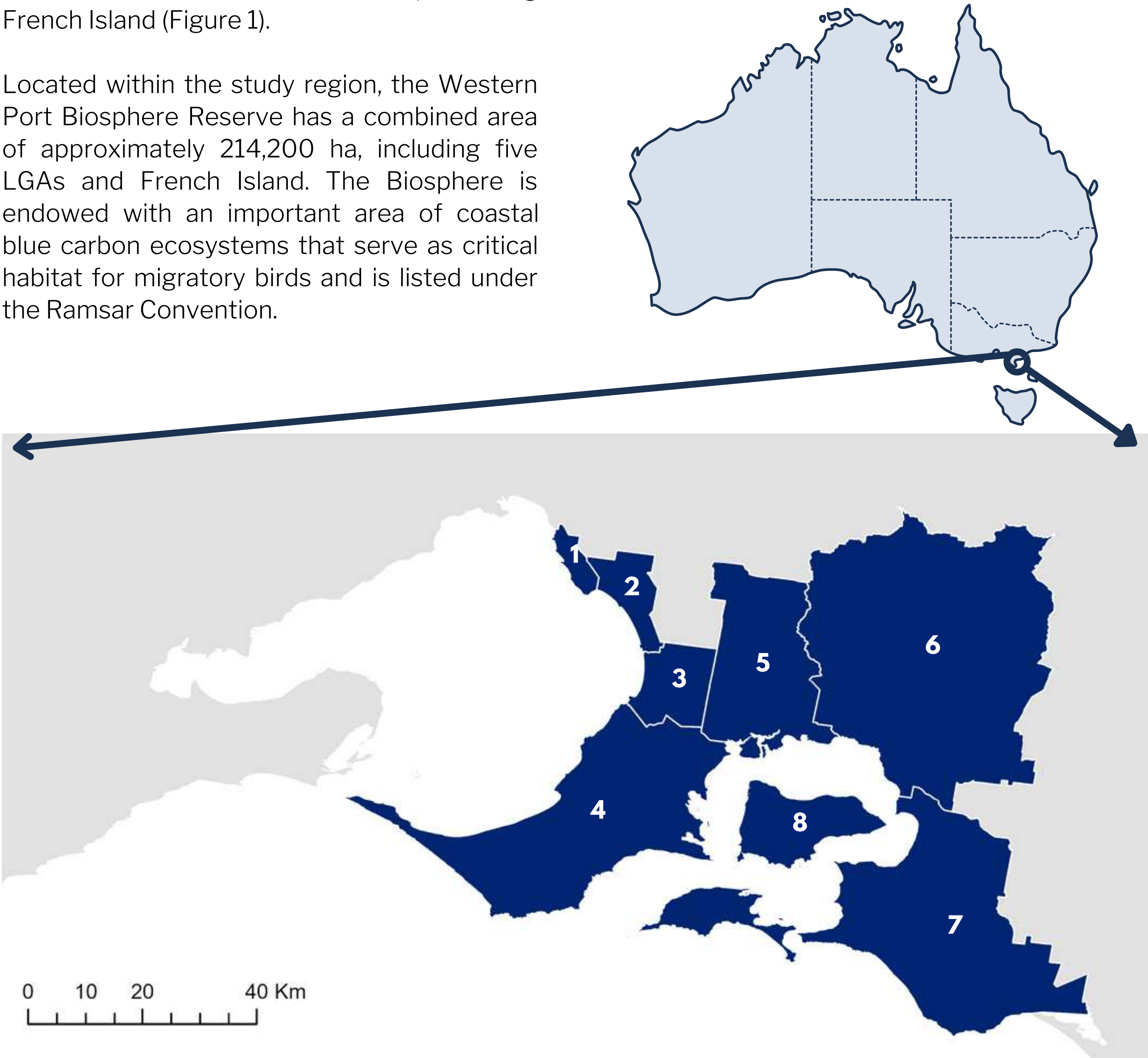


Figure 1. Map of Australia with an insert for the state of Victoria showing the regions included in this study: 1: City of Bayside, 2: City of Kingston, 3: City of Frankston, 4: Mornington Peninsula Shire, 5: City of Casey, 6: Cardinia Shire, 7: Bass Coast Shire, and 8: French Island.

historic distribution of seagrasses along Victoria's coastline, which is limited to different efforts to map seagrasses in Western Port and Port Phillip Bays. In this case, we used spatial data available for Port Phillip Bay (Lynch 1966) and Western Port Bay (Wilkinson et al. 2016), in combination with Australia-wide data available in the Seamap database (Lucieer et al. 2019) to understand the past and current distribution of seagrasses in the study region. Spatial analyses were undertaken in ArcGIS Pro 2.4.3 (ESRI 2011) and R version 3.6.1 statistical software (R Core Team 2019).

Estimating ecosystem services

We followed the approach used by Costa et al. (2022) to estimate the role of blue carbon ecosystems within the study area. This approach uses *existing information* on the ecosystems services provided by Victorian blue carbon ecosystems and focuses on five ecosystem services* :

Carbon sequestration

Nitrogen fixation

Commercial fisheries

Recreational fisheries

Coastal protection

*Although blue carbon ecosystems provide a wider range of ecosystem services (e.g., biodiversity enhancement, cultural values, recreation, eco-tourism), the lack of available data prevents us from including the full set of ecosystem services in our analysis.

Carbon stocks and sequestration

We focused on the soil carbon pool since >70% of the carbon from coastal wetlands is captured and stored there. Information on soil carbon stocks was taken from Ewers Lewis et al. (2020), which conducted a detailed study on blue carbon stocks across 96 coastal wetland sites in Victoria. In addition, Ewers Lewis et al. (2020) mapped soil carbon stocks (down to 30 cm deep in the sediment) and combined them with different environmental variables to understand the main drivers explaining carbon variability along Victoria's coastline. Therefore, we used the data available in Ewers Lewis et al. (2018, 2020) to calculate the soil carbon stocks for this study region.

We used existing soil blue carbon datasets collected in Victoria (Ewers Lewis et al. 2018, Serrano et al. 2019, Gulliver et al. 2020) to estimate carbon sequestration within the study area. Then, we combined the soil carbon sequestration data (see below) with the area of each blue carbon ecosystem site to calculate the potential carbon accumulated per year:

SALTMARSH

- Natural: 0.66 tonnes C ha^{-1} yr^{-1} or 2.42 tonnes CO_2 ha^{-1} yr^{-1} (Ewers Lewis et al. 2018, 2020).
- Restored: 0.54 tonnes C ha^{-1} yr^{-1} or 1.98 tonnes CO_2 ha^{-1} yr^{-1} (Gulliver et al. 2020).

SEAGRASSES

- Natural: 0.5 tonnes C ha^{-1} yr^{-1} or 1.87 tonnes CO_2 ha^{-1} yr^{-1} (Serrano et al. 2019).
- Restored: Seagrass restoration has not been included due to the lack of additionality data from the restoration of this blue carbon ecosystem (see Roadmap Action 1.4).

MANGROVES

- Natural: 1.74 tonnes C ha^{-1} yr^{-1} or 6.38 tonnes CO_2 ha^{-1} yr^{-1} (Ewers Lewis et al. 2018, 2020).
- Restored*: 2.7 tonnes C ha^{-1} yr^{-1} or 9.9 tonnes CO_2 ha^{-1} yr^{-1} (Carnell et al. 2022a).

*Values measured at the restored mangroves of Stony Creek backwash (Port Phillip Bay), which have relatively high sedimentation rates and organic carbon inputs.

To estimate the potential carbon value generated by restored ecosystems, we assumed a project crediting period of 25 years and a 100 years permanence period (Clean Energy Regulator 2022a). Then, sequestration rates were transformed into tonnes CO_2e ha^{-1} yr^{-1} using 3.67 as a conversion factor (i.e., represents the molecular weight ratio of CO_2 to C). Finally, to estimate the potential Australian Carbon Credit Units (ACCUs) generated by each three management scenarios considered (see Table 2), we used three carbon price scenarios to account for the variability in ACCUs prices in Australia:

- average price of AU$16.14 per tonne, based on the mean carbon price in Australia in 2020 (Clean Energy Regulator 2020).
- carbon price of AU$35.10 per tonne, based on the carbon price in Australia in June 2022 (available at ACCUs: June Quarter 2022).
- ·carbon price of AU$47 per tonne, based on the carbon price in Australia in December 2021 (Clean Energy Regulator 2022b).

Nitrogen fixation

We combined nitrogen sequestration data collected within blue carbon ecosystems in Port Phillip and Western Port Bays (Carnell unpublished data, Carnell et al. 2022b; Table 1) with the area covered by each blue carbon ecosystem in the study region to estimate the nitrogen sequestration potential within existing and restored ecosystems.

Table 1. Nitrogen sequestration rates (tonnes N ha^{-1} yr^{-1}) collected within Victorian blue carbon ecosystems (Carnell unpublished data, Carnell et al. 2022b).

Ecosystem	Port Phillip Bay	Western Port Bay
Mangroves	0.165 ± 0.076	0.013 ± 0.002
Saltmarshes	0.051 ± 0.010	0.115 ± 0.039
Seagrasses	0.012 ± 0.002	0.008 ± 0.001

Commercial fisheries

We used data on the average fish abundance and biomass enhancement for Australian coastal wetlands to estimate the potential benefit of blue carbon ecosystems within the study region to commercial fisheries (Jänes et al. 2020b, 2020a): 19,234 individuals ha^{-1} yr^{-1} (or 265 kg ha^{-1} yr^{-1}) for mangroves; 1,712 individuals ha^{-1} yr^{-1} (or 64 kg ha^{-1} yr^{-1}) for saltmarshes; and 55,589 individuals ha^{-1} yr^{-1} (or 4,064 kg ha^{-1} yr^{-1}) for seagrasses. Then, combined this information with the area of each blue carbon ecosystem site to estimate the potential fisheries enhancement and value per year for each blue carbon ecosystem.

Recreational fisheries

We combined data from the fish recreational catch (kg) of finfish and non-fish species in Victoria (Henry and Lyle 2003) with the average contribution from each blue carbon ecosystem estimated by Jänes et al. (2020a): 3% for mangroves, 3% for saltmarshes and 14% for seagrasses. Then, this value was divided by the total distribution of each blue carbon ecosystem in Victoria. Finally, we combined this information with the area of each blue carbon ecosystem site to estimate the potential contribution of the ecosystem to recreational fisheries.

Coastal protection

The potential coastal protection benefit generated by mangroves, saltmarshes, and seagrasses was estimated as per Costa et al. (2022). For that, we used the current distribution of blue carbon ecosystems (Boon et al. 2011, Lucieer et al. 2019) and the 2021 land use property dataset. This assessment considered the average number of properties within a 1 km distance from blue carbon ecosystems that would benefit from the presence of coastal vegetation.

Identifying areas available for blue carbon restoration and their potential ecosystem services

We adapted the modelling approach used in previous blue carbon restoration studies (Moritsch et al. 2021, Carnell et al. 2022b, Costa et al. 2022a) to identify potential areas for restoration of mangroves and saltmarshes using three different management scenarios (Figure 2, Table 2):

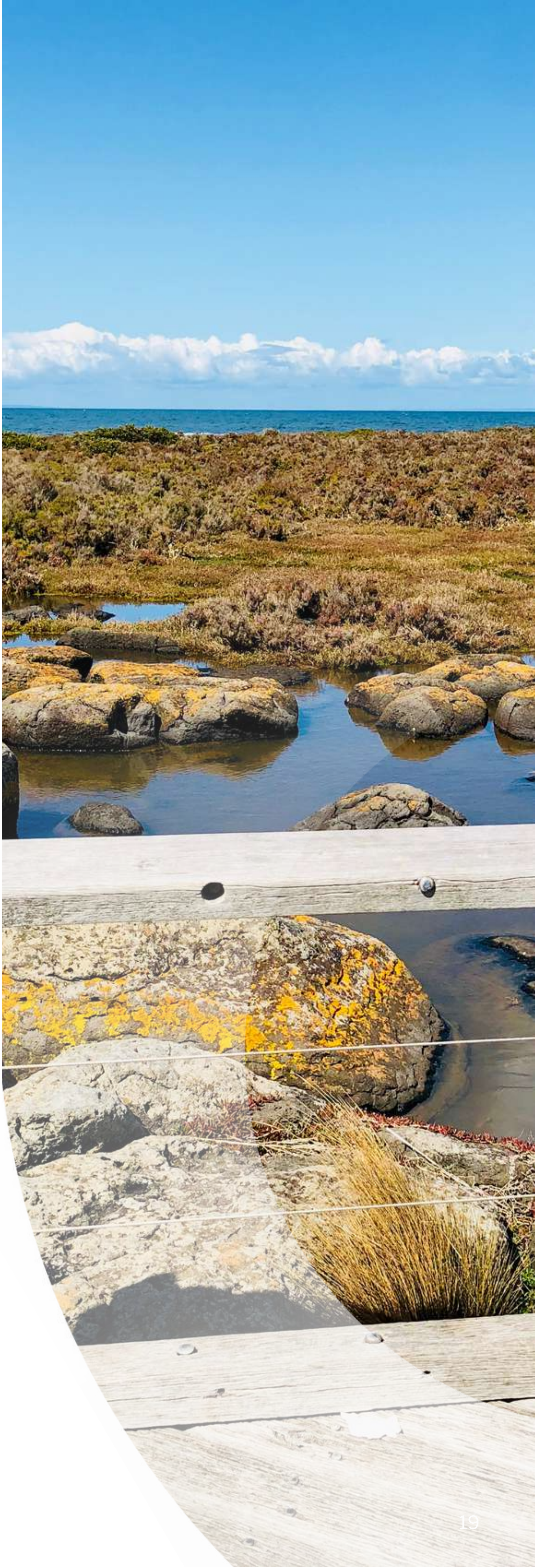
- **Tidal reinstatement**
- **Fencing**
- **Managed retreat to sea-level rise**

Then, we calculated the potential benefits generated by restored blue carbon ecosystems for the three management actions. In the case of carbon sequestration, we followed the assumptions from the ERF's 'Tidal restoration of blue carbon ecosystems method', and applied a 5% discount rate on the carbon sequestered to account for any losses in the system (Clean Energy Regulator 2022a). Furthermore, we assumed that restored ecosystems would start accumulating carbon from year 0 following the management action (Sasmito et al. 2019, Duarte et al. 2020, Gulliver et al. 2020, Carnell et al. 2022b).

Several considerations were taken into account to guide and adjust our analysis of blue carbon opportunities from restoration:

- Management scenarios: Only three restoration management scenarios were considered in this study. Tidal reinstatement is a management action currently eligible to generate ACCUs under the Emissions Reduction Fund (Clean Energy Regulator 2022a). Fencing and managed retreat are additional restoration actions currently being considered by blue carbon experts and proposed as potential new methods to the Department of Climate Change, Energy, the Environment and Water. Although alternative restoration scenarios could potentially be implemented in the region (Kelleway et al. 2020), we still lack data on their scale of opportunity and areas available for restoration.

- Seagrass restoration opportunities: We only explored blue carbon opportunities from the restoration of mangroves and saltmarshes, as large uncertainties still exist on the identification of seagrass areas to be restored. Despite historical data exists on the past distribution of seagrass beds in the region (e.g., Lynch 1966, Blake and Ball 2001, Jenkins et al. 2015), it only enables us to get an idea of the seagrass extent lost, without indicating potential areas for seagrass restoration.



Additional challenges to predicting seagrass restoration opportunities include a lack of understanding of (a) the main drivers of degradation and how to effectively address them (e.g., improve turbidity and water quality), (b) the most effective/successful seagrass restoration techniques for the specific species present in the region, and (c) the associated costs of implementing a seagrass project. Several studies (e.g., Hu et al. 2021, Dalby et al. 2022) and local initiatives by the Western Port Seagrass Partnership and the Seagrass Restoration Network are developing new approaches to identify potential areas for seagrass restoration and testing the best management actions.

- Areas amenable for restoration: We excluded land use categories with areas non-amenable to restoration (i.e., areas that are highly unlikely to be converted back to coastal wetlands such as roads, houses, airports). Hence, only the following land use categories were considered as amenable for restoration: vacant residential englobo land (102), vacant residential rural (103), separate house and curtilage (111 and 117), miscellaneous building on rural residential land (151), vacant industrial englobo land (301), vacant land mining unspecified (482), native vegetation and agriculture/livestock/in-water aquaculture (500-582), vacant land (600), water catchment area (640), water supply (64), rural and community camps (751), water sports (814, 824), bike track/walking trails (829), culture recreation and sport (837), parks and gardens (844), and protected areas and conservation (900-930, 932-991).

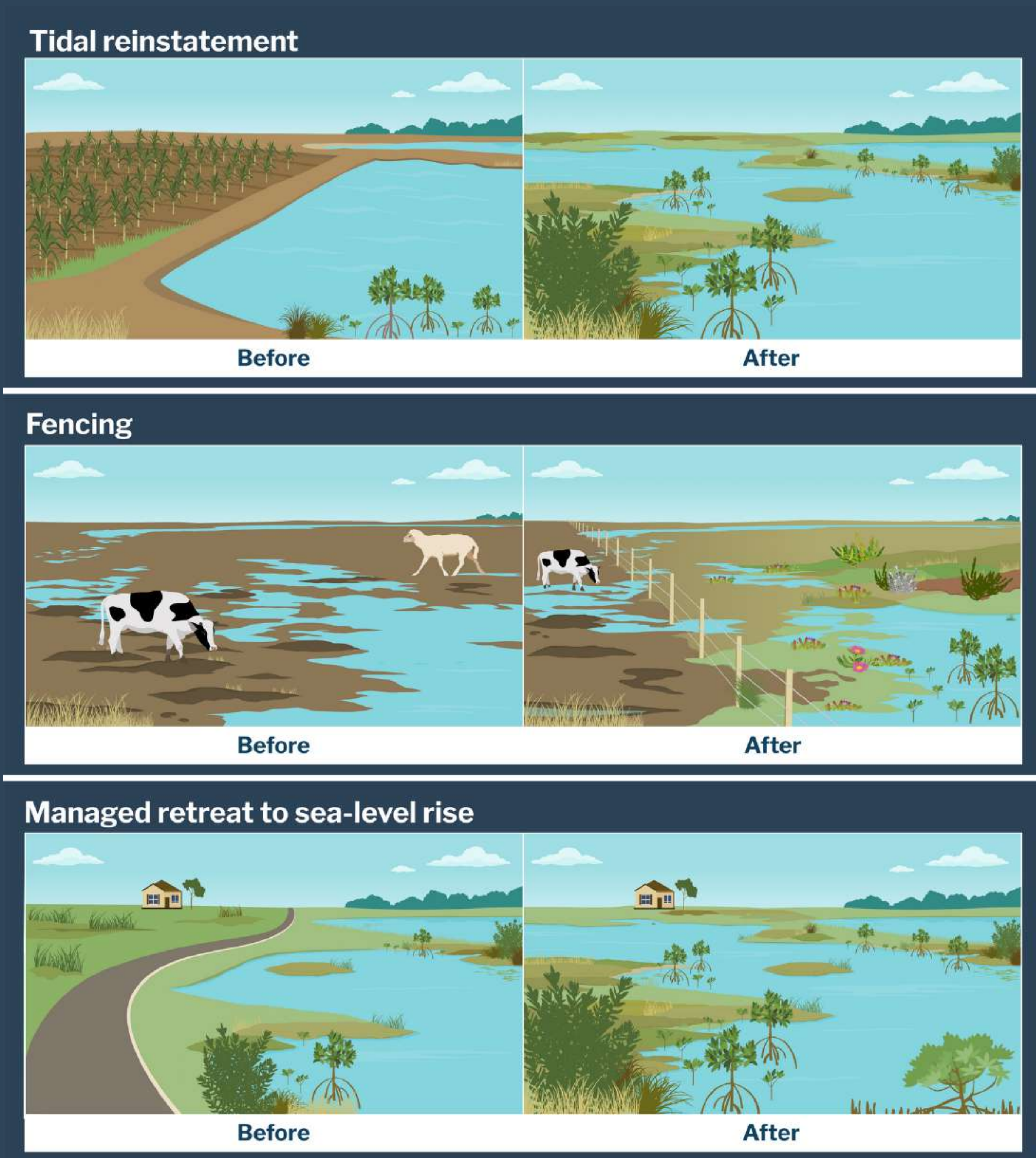


Figure 2. *Graphical representation of the three management actions considered in this study: (1) Tidal reinstatement, (2) Fencing, and (3) Managed sea-level retreat. Panels on the left illustrate the coastal ecosystem before restoration, while those on the right illustrate the potential outcomes after implementing each of the management actions.*

Table 2. Description of the three management scenarios considered in this study, including rationale, methods, and assumptions. Adapted from Costa et al. (2022b).

Scenario	Background, Methods & Assumptions
Tidal reinstatement	The reintroduction of tidal flows has been identified as one of the main management activities to restore coastal wetlands in Australia (Kelleway et al. 2020) and Victoria (Moritsch et al. 2021). Hence, in 2022 the tidal reinstatement (via levee removal) was included in the Emissions Reduction Fund as an eligible management action for the issuance of Australian Carbon Credit Units (ACCUs; (Clean Energy Regulator 2022a). The main assumptions for this management scenario were: 1. The return of tidal exchange enables the passive restoration of mangroves and saltmarshes. 2. The area available for restoration was assessed as per Moritsch et al. (2021) and Costa et al. (2022). This assumes that only areas within 1 km of existing levees with elevation ranging from 0 to 1 m will potentially inundate and lead to the passive restoration of mangroves and saltmarshes. This approach may under- or overestimate the inundation extent in certain areas, and therefore, does not replace a hydrological model at the site level before undertaking a blue carbon project. 3. The return of the tidal exchange will not lead to changes in existing coastal wetlands. This scenario only includes the mapped levees along Victoria's coastline (Department of Environment Land Water and Planning 2018a), which can potentially underestimate the area available for restoration under this scenario (considering there might be non-mapped levees also in the area).
Fencing	Feral animals and livestock can substantially reduce the capacity of saltmarshes to deliver ecosystem services (Limpert et al. 2021) by causing soil erosion and preventing vegetation growth (Mihailou and Massaro 2021, Waltham and Schaffer 2021). Therefore, fencing has been identified as a low-cost management action to restrict animals from accessing and degrading coastal wetlands. Here, we modelled restoration through the fencing of degraded mangrove and saltmarsh areas that are currently being used as pasture or grazing lands. We based our analysis on where these ecosystems existed historically, but do not exist in their current distribution, using the pre-European distribution of mangroves and saltmarshes (Boon et al. 2011) and the most recent land use cover data available for Victoria (Department of Environment Land Water and Planning 2018b). The main assumptions of this management scenario were: 1. Installing a fence around the perimeter of the area to be restored would remove grazing and allow mangroves and saltmarshes to recover over time. 2. A major limitation of this analysis is the lack of information on the locations of existing fences in the study region.

Scenario	Background, Methods & Assumptions
Managed sea-level retreat	Inundation through sea level rise is likely to trigger the loss of coastal wetlands in several locations along the coastline; however, it also represents an opportunity for these ecosystems to expand their distribution. We used the predicted inundation extent from sea level rise plus storm surge in the years 2040 (20 cm), 2070 (47 cm), and 2100 across Victoria (82 cm) (Department of Environment Land Water and Planning 2018c) to estimate the potential area available for restoration and creation of saltmarshes and mangroves through the gradual inundation of sea level rise. In this case, we used the pre-European distribution of mangroves and saltmarshes (Boon et al. 2011) to identify areas amenable for restoration under the early signs of sea level rise, while also allowing for additional creation of saltmarshes in areas inundated by sea level rise from 2070 and 2100 (Moritsch et al. 2021, Costa et al. 2022a). The main assumptions in this scenario were: 1. Restoration would start with early signs of sea level rise in 2040, followed by late signs in 2070 and 2100. 2. Pre-European distribution would be restored in 2040 with the early signs of sea level rise, followed by inundation outside historic distribution from 2070 and 2100 (Department of Environment Land Water and Planning 2018c). 3. No additional levees or sea wall fortifications will be built to limit sea level rise inundation.

Results & Discussion

Results & Discussion

Past and current distribution of blue carbon ecosystems

Before European settlement, Western Port Bay and eastern Port Phillip Bay held approximately 3,280 ha of saltmarshes and 1,927 ha of mangrove forests (Figure 3). Although there is no information on the pre-European seagrass distribution in Victoria, records from the 1960s and 1970s in Western Port and Port Phillip Bays (Lynch 1966, Wilkinson et al. 2016) suggest this region held approximately 10,704 ha of seagrass beds (Figure 3).

According to data on pre-European distribution, French Island and the City of Casey were the regions with the largest (> 3,000 ha) cover of blue carbon ecosystems (results for each council are available in the Information Sheets included in this report). The City of Frankston showed no pre-European distribution of blue carbon ecosystems within its boundaries, while Bayside and the City of Kingston registered only seagrasses.

The best available spatial information indicates Western Port Bay and eastern Port Phillip Bay currently hold 24% of Victoria's coastal wetlands (Costa et al. 2022b); including approximately 2,750 ha of saltmarshes, 1,930 ha of mangroves forests, and 14,945 ha of seagrass beds (Figure 3 and 4). Across the region, saltmarsh and mangrove habitat has declined by approximately 16% and 5%, respectively, while seagrass distribution has increased by approximately 40% (Figure 3). However, due to the natural spatial and temporal fluctuations (seasonal-interannual) of seagrass meadows, it is complex to fully understand the gains and losses through time.

Based on our results, French Island, Bass Coast, and the Mornington Peninsula are the regions with the largest current distribution of blue carbon ecosystems, with seagrass meadows representing most of such extent.

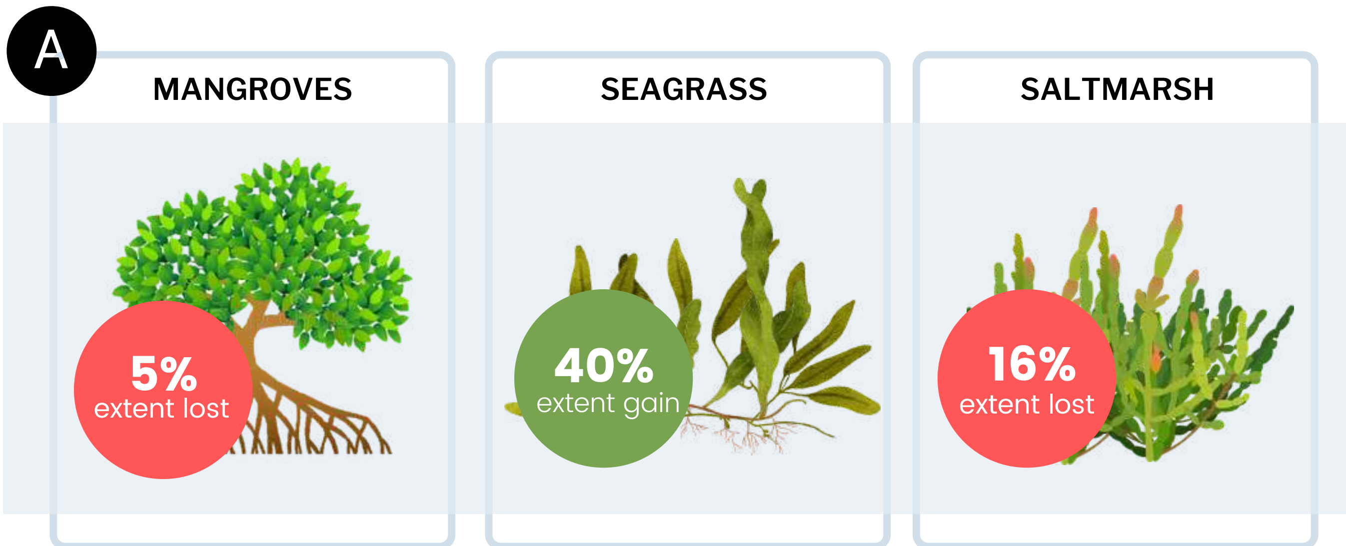
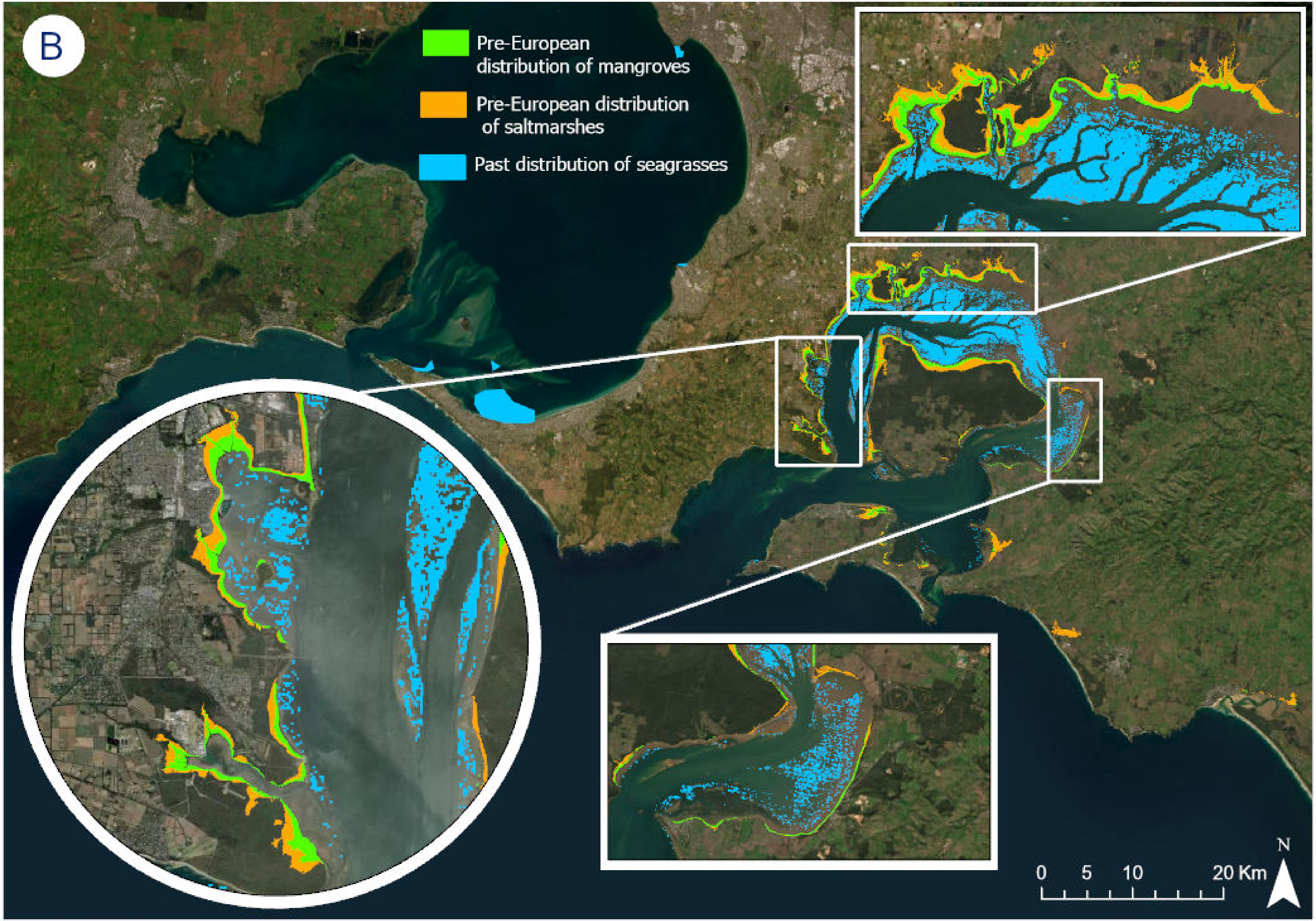


***Figure 3.** This page: (A) Percentage change in saltmarsh, mangrove, and seagrass cover within Western Port Bay and eastern Port Phillip Bay region based on existing spatial data. Next pages: Past (B) and current (C) distribution of blue carbon ecosystems within the region, including insets for different areas. Specific maps for each council are available in the Information Sheets included in this report.*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Pre-European distribution of mangroves
Pre-European distribution of saltmarshes
Past distribution of seagrasses
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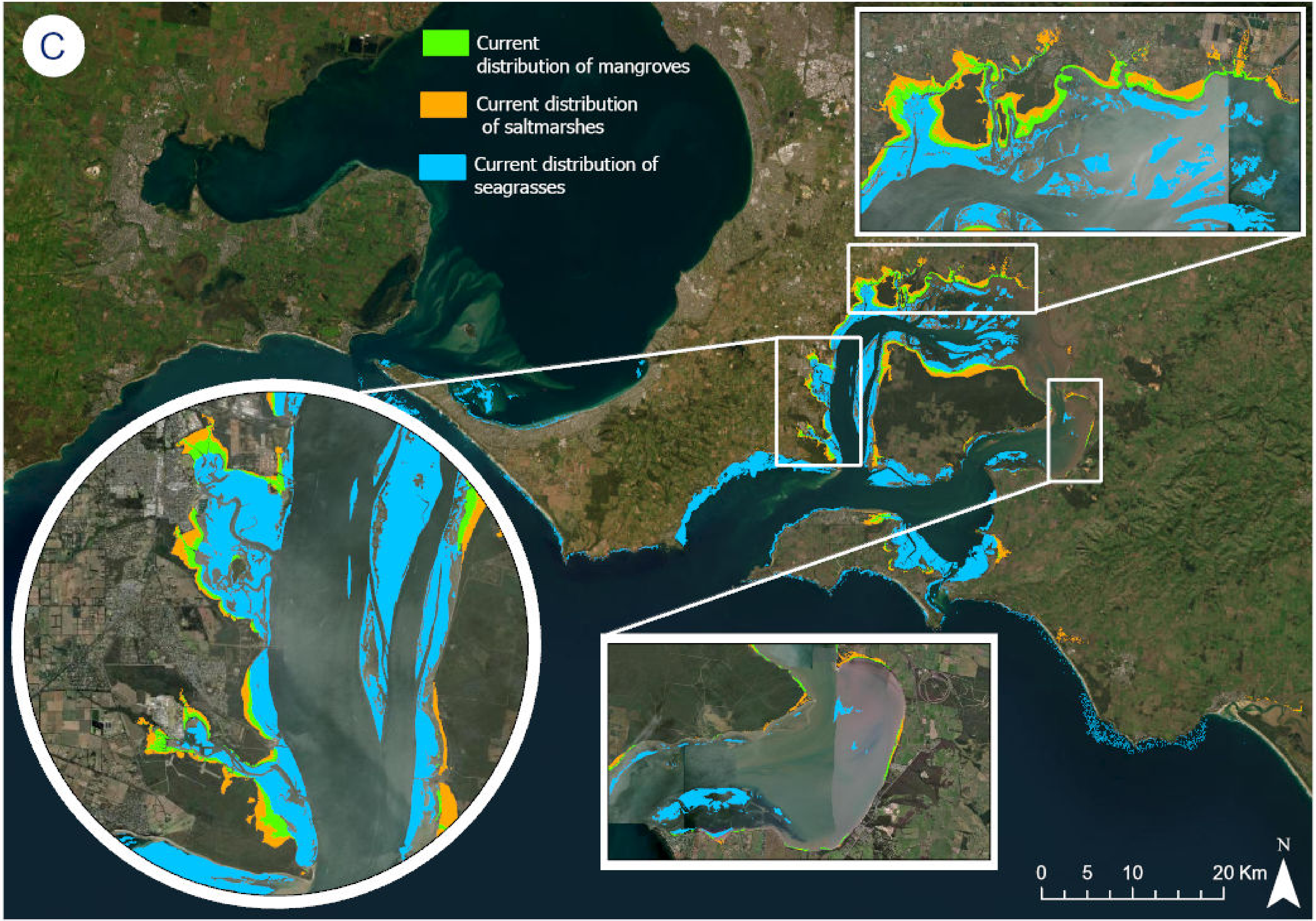

C
Current distribution of mangroves
Current distribution of saltmarshes
Current distribution of seagrasses
0 5 10 20 Km
N

Councils with the largest historical extent of blue carbon ecosystems had lost the most extent since European settlement due to a diverse range of anthropogenic (e.g., change in land use) and natural factors. The historical and current cover of blue carbon ecosystems for each council is available in Information Sheets included in this report.

Despite using the best available spatial information and datasets across the region, this study highlighted the lack of a systematic and continuous approach to monitor these blue carbon ecosystems and account for multi-decadal changes in their extent (Roadmap Actions 1.1 and 1.2). In recent years, our ability to monitor coastal ecosystems at different spatial scales has increased substantially allowing us to better understand changes over time and conditions (Lymburner et al. 2020, Navarro et al. 2020, 2021, Lee et al. 2021, Murray et al. 2022, Dalby et al. 2022). These approaches could be replicated in the study region and Victoria.

For example, a recent study published by Dalby et al. (2022) evaluated temporal and spatial changes of seagrasses within Western Port Bay. The authors found that contemporary seagrasses are predicted to occur within 22,200 ha. The authors also found that seagrasses in the region showed a net gain of 9,500 ha in the past 20 years alongside an expansion of their distribution. This is a good example of how new technologies such as remote sensing can play a significant role in monitoring blue carbon ecosystems over time, and therefore, guide future decisions and management actions.

Additionally, two recent studies conducted in Victoria have used existing data on the threats, land use cover and historical distribution of coastal wetlands to classify these ecosystems into several health categories: collapsed, high disturbance, medium disturbance, low disturbance, and natural (Carnell et al. 2022b, Costa et al. 2022b). The condition map developed for Victoria (and other maps by Costa et al. 2022b) is available in the CoastKit platform from Victoria's Department of Energy, Environment and Climate Action (DEECA) and can be used to guide decision-making to conserve and restore existing coastal wetlands. Furthermore, while recent studies have shown the potential contribution of macroalgae to carbon sequestration (Krause-Jensen and Duarte 2016, Ortega et al. 2019), this study has only focused on mangroves, saltmarshes, and seagrasses due to the large uncertainties that remain on how to include macroalgae in blue carbon budgets and assessments.

Figure 4. *Abundant plant species occurring within Western Port's blue carbon ecosystems. Saltmarshes (A) Salicocornia quinqueflora, (B) Distichlis distichophylla, and (C) Sueda australis; mangroves (D) Avicennia marina; and seagrasses (E) Zostera muelleri and (F) Amphibolis antarctica. Photos: Blue Carbon Lab.*

Blue carbon stocks and sequestration rates in existing coastal ecosystems

Victoria is home to ~80,000 ha of coastal wetlands holding carbon stocks in the range of ~20-40 million tonnes of carbon (Serrano et al. 2019, Young et al. 2021). Western Port Bay and eastern Port Phillip Bay encompass approximately 31.5% of Victoria's blue carbon stocks, totalling more than 2 million tonnes of organic carbon (or 8.9 million tonnes CO_2e).

At a council scale, French Island, Bass Coast, and the Mornington Peninsula are the regions with the highest blue carbon stocks (Figure 5). This information is based on previous studies in the region showing that carbon stocks in the top 30 cm of the sediment vary from 65.6 ± 4.17 tonnes C ha^{-1} in mangroves, 87.1 ± 4.90 tonnes C ha^{-1} in saltmarshes, and 24.3 ± 1.82 tonnes of C ha^{-1} in seagrasses (Ewers Lewis et al. 2018, Ewers Lewis et al. 2020).

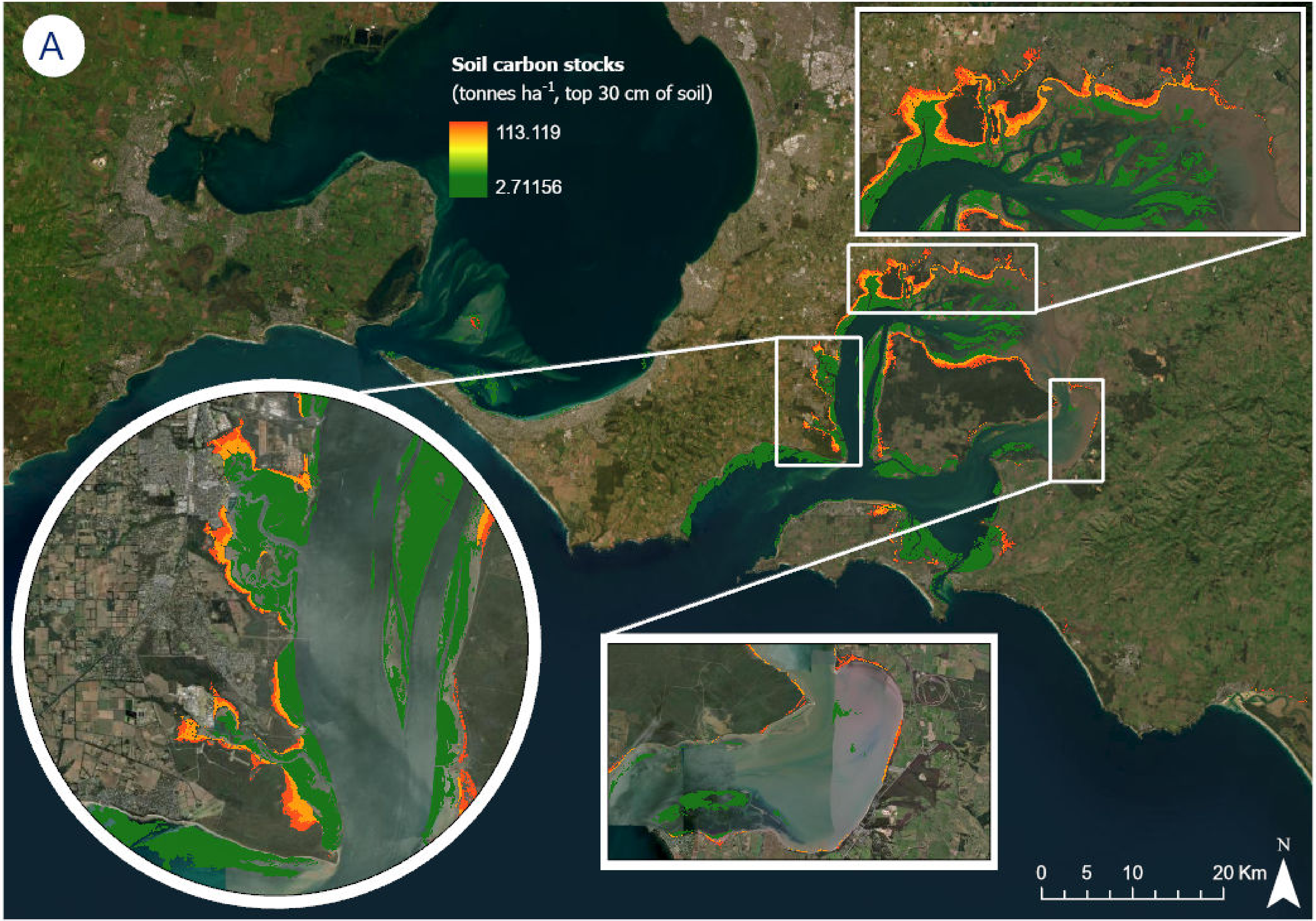
Other ecosystem services provided by existing blue carbon ecosystems

Additional to carbon storage, these coastal wetlands provide an array of co-benefits including carbon and nitrogen sequestration, commercial fisheries, recreation, and coastal protection (Figure 6). Although these ecosystem services are usually difficult to quantify, we used existing data to provide a first-pass assessment for the region.

Overall, carbon sequestration varies from 3,358 tonnes C yr^{-1} for mangroves (1,930 ha), 1,812 tonnes C yr^{-1} for saltmarshes (2,746 ha), and 7,472 tonnes C yr^{-1} for seagrasses (14,945 ha). In addition, these ecosystems protect on average more than 40,000 properties, while also maintaining water quality and enhancing fisheries (Figure 6). High-resolution maps of the ecosystem services are available for each council in the Information sheets.

The provision of ecosystem services varies substantially throughout the coastline (Carnell et al. 2022b, Costa et al. 2022b) and although some councils might not have a significant cover of coastal wetlands, they do provide important services to the coastal communities. For example, although the Bayside council only holds approximately 12 ha of seagrass meadows, they can enhance fisheries by more than 50,000 kg fish yr^{-1} and protect over 20,000 properties (on average) within 1 km of the coastline. Regardless of the extent of blue carbon ecosystem within each council, it is therefore critical for LGAs to work together with the state government and local community groups to support the conservation of coastal wetlands and the protection of all the ecosystem services they provide in the region.

***Figure 5.** Next page: Variation of carbon stocks within the Western Port Bay and eastern Port Phillip Bay region. (A) Blue carbon stocks in the top 30 cm of the sediment within the study region at a 25 m^2 resolution (tonnes ha^{-1}; Ewers Lewis et al., 2020). Raster files available for download from* https://doi.org/10.7910/DVN/UDOAUT. *(B) Total blue carbon stocks within the coastal wetlands in the region, classified from higher to lower stocks (based on data carbon from Ewers Lewis et al. 2018, and spatial data from Boon et al. 2011 and Lucieer et al. 2019).*


A
Soil carbon stocks
(tonnes ha-1, top 30 cm of soil)
113.119
2.71156
0
5
10
20 Km
N

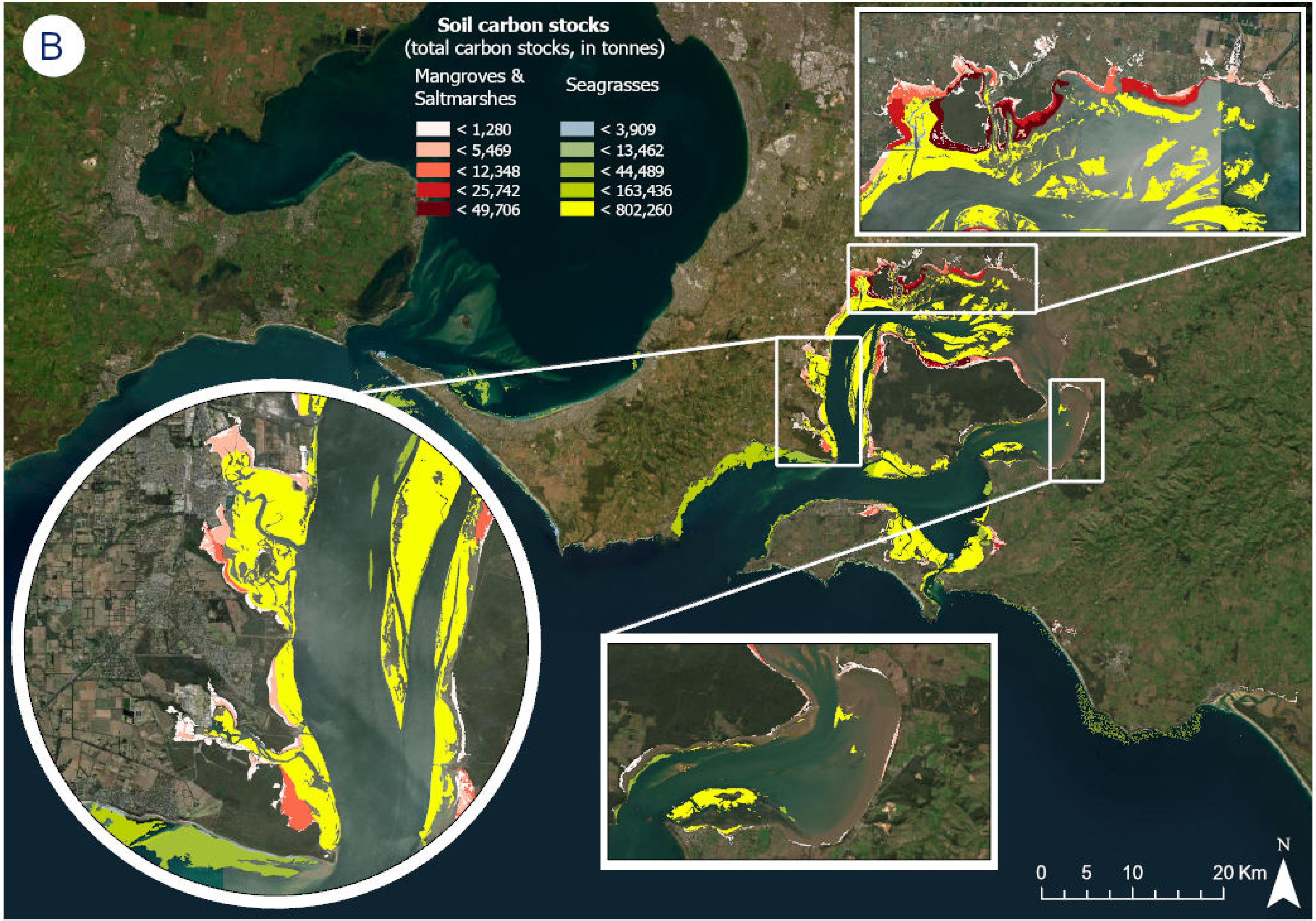

B
Soil carbon stocks
(total carbon stocks, in tonnes)
Mangroves & Saltmarshes
Seagrasses
< 1,280
< 5,469
< 12,348
< 25,742
< 49,706
< 3,909
< 13,462
< 44,489
< 163,436
< 802,260
0 5 10 20 Km
N

Figure 6. *Ecosystem services provided by coastal wetlands in Western Port Bay and eastern Port Phillip Bay, based on Costa et al. (2022): (1) Carbon sequestration (tonnes C yr^{-1}), (2) Nitrogen fixation (tonnes N yr^{-1}), (3) Commercial fisheries (kg fish yr^{-1}); (4) Recreational fisheries (kg fish yr^{-1}); and (5) Coastal Protection (average number of properties within 1 km from existing coastal wetlands). Co-benefits were calculated based on Costa et al. (2022). Values for each council are detailed in the Information sheets.*

Areas available for blue carbon restoration and their potential ecosystem services

We used existing information on habitat distribution, management actions, and land use cover (Boon et al. 2011, Department of Environment Land Water and Planning 2018a, 2018c, 2018b, Carnell et al. 2019, Moritsch et al. 2021) to estimate the potential area available for mangrove and saltmarsh restoration in Western Port Bay and eastern Port Phillip Bay.

Across the three restoration management actions evaluated in this study, there is potential to restore almost 800 ha of blue carbon ecosystems in the region, with an additional 9,000+ ha potentially available from managing future sea-level rise inundation (Figure 7). Given their ecological importance and potential for climate change adaptation and mitigation, it is key to understand how restoration could influence the provision of ecosystem services to coastal communities.

Managed sea-level retreat

From the three management actions explored, the managed sea-level retreat was the restoration approach with the highest opportunities throughout the study region (> 10,000 ha by 2100; Figures 7 and 8), reinforcing the need for councils to plan for future sea-level conditions.

Although sea level rise will cause the loss of many blue carbon sites, there is also great potential for blue carbon ecosystems to expand their distribution to newly inundated areas. Our results showed that managed retreat is a management option available for all councils in the study area, including those with limited or no existing or past distribution of blue carbon ecosystems (i.e., assuming that these ecosystems will expand their distribution outside their historic distribution; Figures 7 and 8). If these areas are colonised by mangroves and saltmarshes from 2040, these ecosystems would generate approximately 18,000 tonnes C yr^{-1}, 1,000 tonnes N yr^{-1}, and 589,000 kg fish yr^{-1}, while also protecting an average of more than 10,000 properties located within 1 km from restored blue carbon ecosystems.

We assumed that low-lying inundated areas would be populated by mangroves and saltmarshes depending on their past distribution; however, future studies could use modelling approaches (such as species distribution models) to understand the likelihood of these areas becoming occupied by these coastal species. In agreement with previous studies (Moritsch et al. 2021, Costa et al. 2022a), the restoration of coastal wetlands via managed sea-level retreat presents an opportunity to develop a new blue carbon method based on this management option.

Tidal Reinstatement

Tidal reinstatement has been identified as one of the main blue carbon restoration approaches in Australia (Kelleway et al. 2020). We found 441 ha of area amenable for tidal reinstatement in the study region (Figure 7). Most of the tidal reinstatement opportunities are located in Casey (142.4 ha), Cardinia (184 ha), and Bass Coast (115 ha).

If restored, these ecosystems would generate approximately 874 tonnes C yr^{-1}, 50 tonnes N yr^{-1}, and > 28,000 kg fish yr^{-1}, while also protecting on average 660 properties located within 1 km of the restored blue carbon ecosystems (Figure 8). It is important to highlight, however, that our results are based on the *existing mapped levees* in Victoria (Department of Environment Land Water and Planning 2018a), which could underestimate the opportunities in the region (considering there might be non-mapped levees also in the area). Future studies, including local feasibility assessments, should consider this limitation to identify potential sites for restoration (see Roadmap Action 4.2).

Fencing

Fencing is a promising low-cost management option to restore coastal wetlands and is starting to be implemented across Victoria (see Box 1; Elschot et al. 2015, Keshta et al. 2020, Janousek et al. 2021). We identified 321 ha of area amenable for restoration through fencing in the study region (Figures 7 and 8).

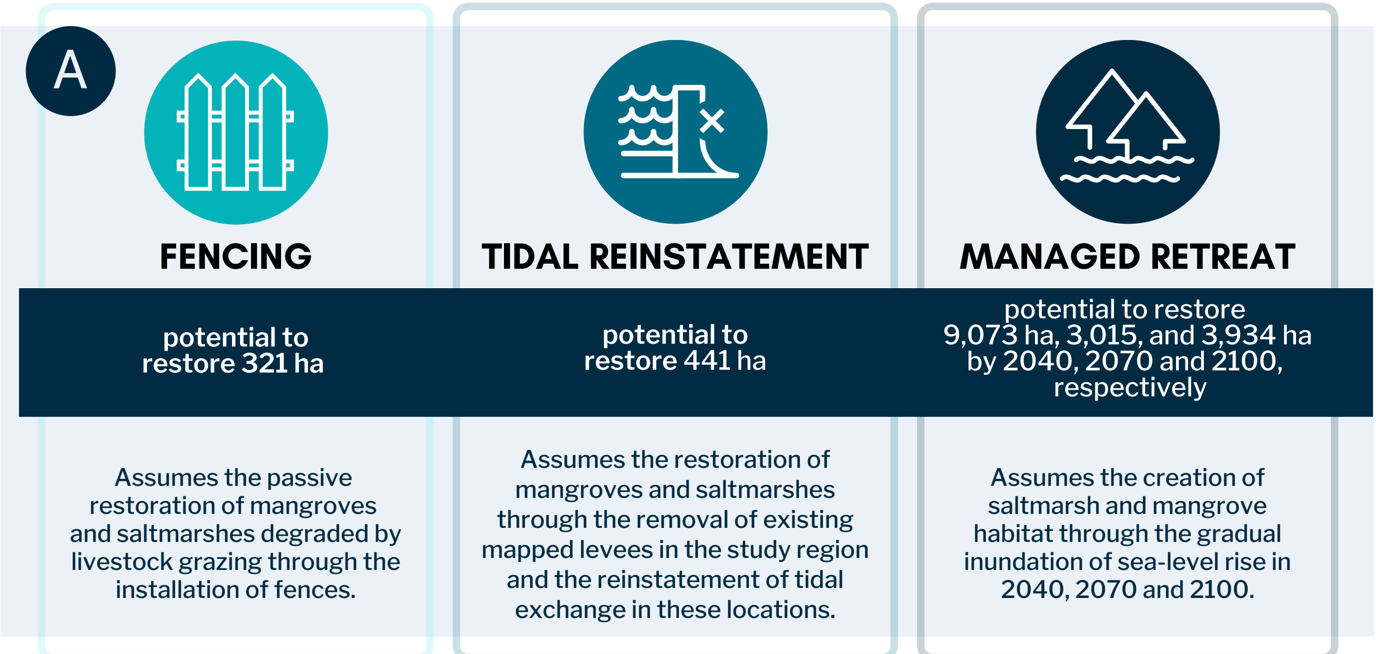
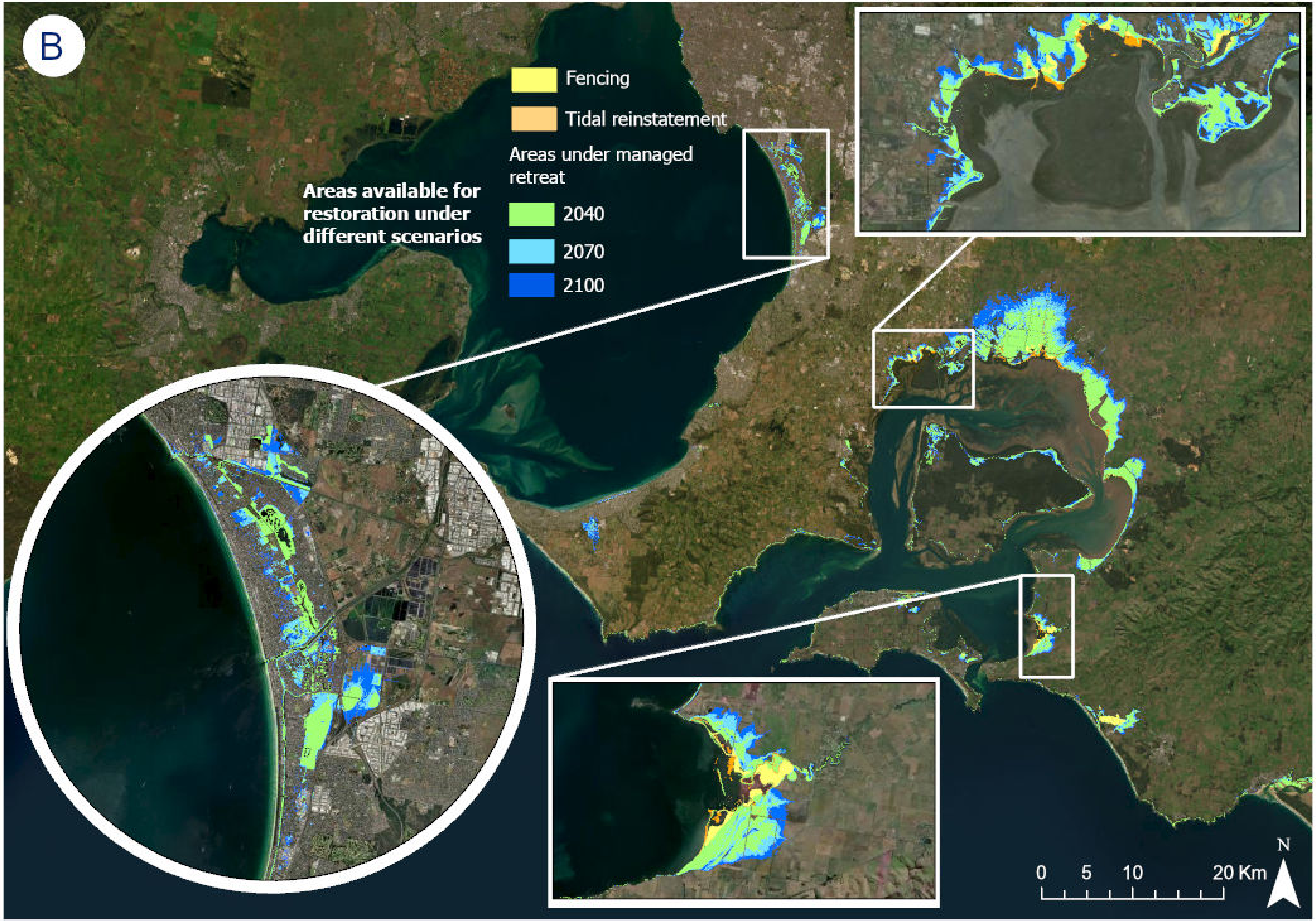


***Figure 7.** This page: (A) Potential area available for restoration in Western Port Bay and eastern Port Phillip Bay, considering three different management actions: (1) fencing, (2) tidal reinstatement, and (3) managed sea-level retreat from 2040, 2070 and 2100. Next page: (B) Distribution of potential areas for restoration within the region, including insets for different locations. Maps for each council are available in the Information Sheets included in this report.*


B
Fencing
Tidal reinstatement
Areas under managed retreat
Areas available for restoration under different scenarios
2040
2070
2100
N
0 5 10 20 Km

BOX 1.

Fencing as a low-cost method to restore blue carbon ecosystems

The Victorian Coastal Wetland Restoration Program (#VicWetlandRehab) is a multi-disciplinary program, including several project partners from academia, government, industry and First Nations peoples, guiding and conducting on-ground restoration of coastal wetlands within Victoria's coastline. So far, the program led by Deakin University's Blue Carbon Lab has already restored 30 ha of coastal wetlands through fencing, demonstrating the potential of this low-cost management action to restore blue carbon ecosystems.

As part of this program, Parks Victoria and local landholders are aiming to install >1,200 meters of fencing to protect 25 ha of saltmarshes from livestock grazing in Western Port. Livestock can significantly damage coastal wetlands ecosystems when they have access through grazing the vegetation and pugging of soil when the area is wet, which can result in extensive erosion, biodiversity loss, and loss of other ecosystem services provided by saltmarshes.

By installing a fence to exclude livestock from coastal wetlands, these ecosystems have the capacity to passively recover without further intervention.

Blue carbon experts in Australia have been working to fulfil knowledge gaps (i.e., the scale of opportunity, willingness from stakeholders) to develop a new blue carbon method under the ERF based on exclusion fencing. Monitoring is currently underway including vegetation surveys and soil carbon assessments, such as carbon stocks, soil accumulation, carbon cycling and greenhouse gas fluxes (carbon dioxide and methane).

More information is available on the program's website or interactive StoryMap.

Exclusion fencing as a low-cost method to restore blue carbon ecosystems.

From this total, opportunities through fencing are limited to Bass Coast (82.3%), Casey (11.53%), Cardinia (5.41%) and French Island (0.72%). If restored, these ecosystems would generate approximately 638 tonnes C yr^{-1}, 37 tonnes N yr^{-1}, and 21,000 kg fish yr^{-1}, while also protecting an average of 581 properties located within 1 km of restored blue carbon ecosystems. Overall, a new low-cost blue carbon method based on fencing is promising because it is low-cost and is likely to have a higher level of landholder support. Such a method would help overcome the complexities and high costs associated with the current ERF's tidal reinstatement methodology (which requires engineering works and hydrological modelling; Clean Energy Regulator 2022).

Combined approaches

The restoration of historically lost coastal wetlands in Western Port Bay and eastern Port Phillip Bay through fencing and tidal reinstatement could lead to ~58,536 tonnes CO_2e and 80,214 tonnes CO_2e, respectively, sequestered in their soils after 25 years (worth AU$2.7 million and $3.7 million AUD, considering carbon price at AU$47 per tonne; Figure 8 and Table 3). If managed sea-level retreat is included as a restoration option, opportunities increase substantially (Figure 8). Table 3 shows detailed results for each region included in this study.

Our analysis only represents the potential financial value of carbon sequestration since the carbon market is the most advanced (Vanderklift et al. 2019, Clean Energy Regulator 2022a, Friess et al. 2022). However, there is a growing opportunity to financially capitalise on other ecosystem services from restored blue carbon ecosystems. For example, fencing alone would deliver a non-market value of AU$3.8 billion per year if coastal wetlands are restored at a large scale in Victoria (including carbon and nitrogen sequestration, fisheries, and coastal protection; Costa et al., 2022b).

Although we still face uncertainties in the financial valuation of many ecosystem services (e.g., nitrogen sequestration, coastal protection, social and recreational values), different approaches have been suggested to quantify the natural capital from coastal wetlands (VERRA 2010, Smart et al. 2020, Canning et al. 2021, Queensland Government 2021), with increasing willingness from buyers to pay a material premium for ACCUs with defined co-benefits, particularly economic and social benefits for First Nations peoples (June Quarter 2022).

The potential value of restored coastal wetlands is a major asset for coastal communities; however, councils should also consider the restoration opportunities from freshwater wetlands (see Box 2).

Our results provide baseline regional-scale information to help guide future restoration projects. However, pre-feasibility assessments need to be conducted at a site-specific level to help the decision-making process and site selection before undertaking a restoration project (see Roadmap Action 4.2). This step is crucial to accurately cost the project needs, including all the management actions and interventions needed to restore the site. Recently, Costa et al (2022b) showed that even for expensive restoration interventions, such as levee removal and bathymetry modifications, the generation of ecosystem services is likely to outweigh the investment costs by the end of the project duration. That said, if only carbon credits are issued, a feasible return on investment might depend on whether the restoration project is at a large scale and whether blue carbon credits attract a premium carbon price (Costa et al. 2022a).

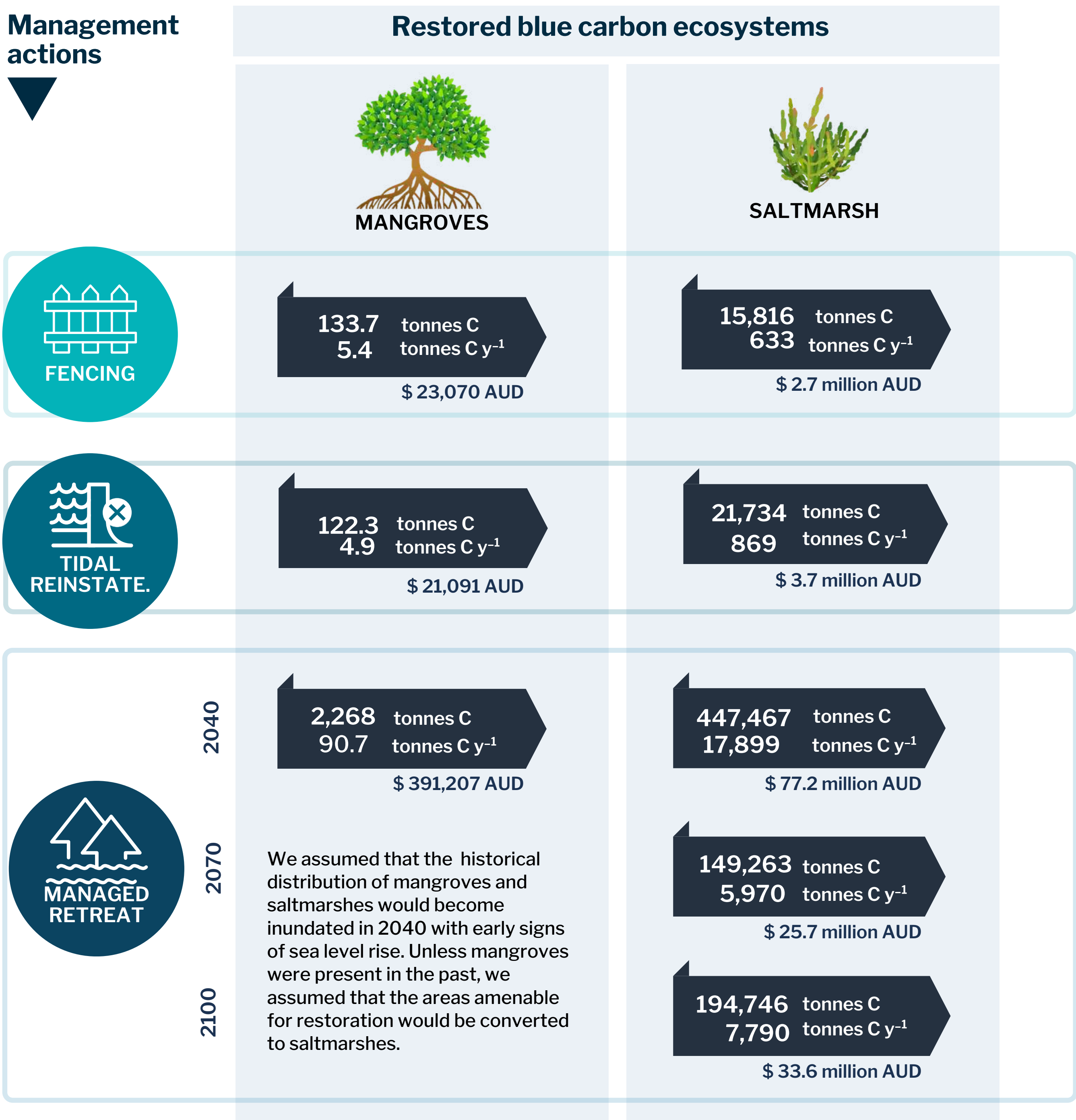


Figure 8. *First-pass estimates of potential carbon gains from mangrove and saltmarsh restoration in the Western Port Bay and eastern Port Phillip Bay region, considering three different management actions; (1) fencing, (2) tidal reinstatement, and (3) managing sea-level rise (SLR) by 2040, 2070, and 2010 (Moritsch et al. 2021). Restoration assumes the recovery of the historic distribution of coastal wetlands (Boon et al. 2011). Soil carbon sequestration data were assumed as: 1.98 and 2.7 tonnes C ha^{-1} yr^{-1} for restored saltmarshes (Gulliver et al., 2020) and mangroves (Carnell, Palacios et al., 2022), respectively, while assuming a 25-years project period. Here, the results show the carbon value based as $47 per tonne of CO_2e (based on Australian values for December 2021). Results for each council are available in Table 3 and Information Sheets included in this report.*

Notes:

- Values are not calculated for seagrass, due to the lack of data on additionality opportunities.
- These results are a representation only, and do not substitute a detailed feasibility assessment.

Table 3. *Potential carbon market value (AUD$) from the restoration of mangroves and saltmarshes through three different management actions (i.e., fencing, tidal reinstatement and managed sea-level retreat) in Western Port Bay and eastern Port Phillip Bay. We used three carbon price scenarios to account for the variability in ACCUs prices (per tonne) in Australia: $16.14, $35.10, and $47; while assuming a 25-years project period. These results are a representation only, and do not substitute a detailed feasibility assessment.*

Council	Restoration management actions		
	Fencing	Tidal reinstatement	Managed sea-level retreat
City of Bayside	NA	NA	2040: $68,607 to $199,786 2070: $27,040 to $78,742 2100: $42,604 to $124,063
City of Kingston	NA	NA	2040: $949,784 to $2.7 million 2070: $461,194 to $1.3 million 2100: $611,811 to $1.7 million
City of Frankston	NA	NA	2040: $659,464 to 1.9 million 2070: $286,662 to $834,765 2100: $393,489 to $1.1 million
Mornington Peninsula Shire	NA	NA	2040: $1.2 to $3.5 million 2070: $536,125 to $1.5 million 2100: $909,979 to $2.6 million
City of Casey	$108,196 to $317,165	$418,798 to $ 1.2 million	2040: $4.3 to $12.7 million 2070: $1.4 to $4.2 million 2100: $3.2 to 9.3 million
Cardinia Shire	$51,044 to $148,643	$539,072 to $1.5 million	2040: $10.3 to $30.2 million 2070: $3.8 to $11.2 million 2100: $4.1 to $12 million
Bass Coast Shire	$778,035 to $2.2 million	$336,790 to $980,739	2040: $7.4 to $ $21.7 million 2070: $1.6 to $4.7 million 2100: $1.5 to $4.5 million
French island	$6,782 to $19,759	NA	2040: $1.5 to $4.4 million 2070: $590,279 to $1.7 million 2100: $661,626 to $1.9 million

Caveats

Overall, our study showed that existing and restored blue carbon ecosystems are key assets helping councils within Western Port Bay and eastern Port Phillip Bay to adapt and mitigate climate change. However, we should highlight the main limitations of this study, which will be addressed in the Blue Carbon Roadmap to guide future research and the implementation of blue carbon projects in the study area:

Scale

This study includes a regional-scale assessment to identify potential areas for project implementation. However, selecting specific sites for future restoration projects requires pre-feasibility assessments that consider site-level conditions and cost-benefit analyses (see Roadmap Action 4.2).

Restoration actions

Blue carbon restoration opportunities were only explored for three management scenarios: (1) tidal reinstatement, (2) fencing, and (3) managed retreat (Table 2, Figure 2). While tidal reinstatement is currently an eligible activity under the ERF, fencing and managed retreat are activities with great scalability potential that have been previously proposed and considered by the Department of Climate Change, Energy, the Environment and Water. In the future, alternative restoration actions such as enhancing sediment supply, avoided soil disturbance, revegetation of seagrasses, among others (Kelleway et al. 2020) could be modelled to obtain blue carbon opportunities from a wider range of potential restoration approaches (see Roadmap Actions 4.2).

Maps

Existing blue carbon ecosystems and amenable areas available for restoration were estimated using the best available maps of coastal ecosystems, land use cover, and levees for the study region. Unfortunately, these maps still have spatial gaps that may lead to under- or overestimating the potential benefits provided by existing and restored ecosystems (see Roadmap Action 1.1). Many spatial layers currently used are being improved through new research projects, so we expect that more accurate estimates will be available in the near future.

Seagrass ecosystems

This study did not evaluate the potential blue carbon opportunities and co-benefits from the restoration of seagrass meadows and kelp forests. The large uncertainties on where seagrass and kelp restoration could be implemented limits our capacity to quantify the scale of opportunity, and hence the scope for restoration (see Roadmap Action 1.4).

Despite these limitations, our results provide baseline information to councils to guide future decisions on the importance of conserving and restoring blue carbon ecosystems. With the increasing interest in advancing blue carbon markets in Australia, this study provides the councils within the study region with essential information to guide their next steps. While the first blue carbon method on tidal reinstatement was released in early 2022, registered blue carbon projects are yet to be implemented in Australia. This is likely due to the lack of demonstration projects, the high implementation costs of removing tidal barriers and undertaking hydrological assessments, and many uncertainties faced by landholders relating to the return on investment. In this sense, it is key that new methods being developed consider landholders' willingness to restore blue carbon ecosystems and implement such methods. Regardless of the management scenario, the opportunity to have carbon credits of high value by incorporating additional co-benefits (e.g., nitrogen sequestration, biodiversity) is crucial to increase the financial return and therefore, landholders' amenability towards blue carbon projects.

Detailed results for each management option included in this study and the potential ecosystem services generated by restored blue carbon ecosystems are available in the Information Sheets developed for each council in the study region.

Ecosystem services of restored coastal wetlands

Restoration management actions

Ecosystem service	Wetland	FENCING	TIDAL REINSTATEMENT	MANAGED RETREAT
(1) Nitrogen fixation	Mangrove	0.03 tonnes N y⁻¹	0.02 tonnes N y⁻¹	2040: 0.43 tonnes N y⁻¹
	Saltmarsh	36.7 tonnes N y⁻¹	50.5 tonnes N y⁻¹	2040: 1,005 tonnes N y⁻¹; 331 tonnes N y⁻¹ [2070]; 430 tonnes N y⁻¹ [2100]
(2) Commercial fisheries	Mangrove	525 kg fish y⁻¹	481 kg fish y⁻¹	2040: 8,903 kg fish y⁻¹
	Saltmarsh	20,449 kg fish y⁻¹	28,101 kg fish y⁻¹	2040: 578,546 kg fish y⁻¹; 192,983 kg fish y⁻¹ [2070]; 251,782 kg fish y⁻¹ [2100]
(3) Recreational fisheries	Mangrove	1.02 kg fish y⁻¹	0.95 kg fish y⁻¹	2040: 17.5 kg fish y⁻¹
	Saltmarsh	41.5 Kg fish y⁻¹	57.1 kg fish y⁻¹	2040: 1,175 kg fish y⁻¹; 392 kg fish y⁻¹ [2070]; 511 kg fish y⁻¹ [2100]
(4) Coastal protection	Mangrove	327 properties	335 properties	2040: 1,299 properties
	Saltmarsh	254 properties	325 properties	2040: 10,679 properties; 10,999 properties[2070]; 24,217 properties [2100]

***Figure 9.** Estimate of additional co-benefits (1) Nitrogen fixation (tonnes N yr^{-1}), (2) Commercial fisheries (kg fish yr^{-1}); (3) Recreational fisheries (kg fish yr^{-1}); and (4) Coastal Protection (average number of properties within 1 km from restored coastal wetlands) that mangrove and saltmarsh could generate in Western Port Bay and eastern Port Phillip Bay. We considered three different management actions in this study: (1) installation of exclusion fencing, (2) tidal reinstatement, and (3) managing sea-level rise from 2040, 2070, and 2010. Potential co-benefits are average values from Costa et al. (2022) and represent the combined value for restored mangroves and saltmarshes.*

Notes:
- *Values are not calculated for seagrass, due to the lack of data on additionality opportunities.*
- *Co-benefits from the managed retreat of mangrove forests are only estimated for 2040, because after this period the entire past distribution of mangroves would have already been restored.*

Box 2.

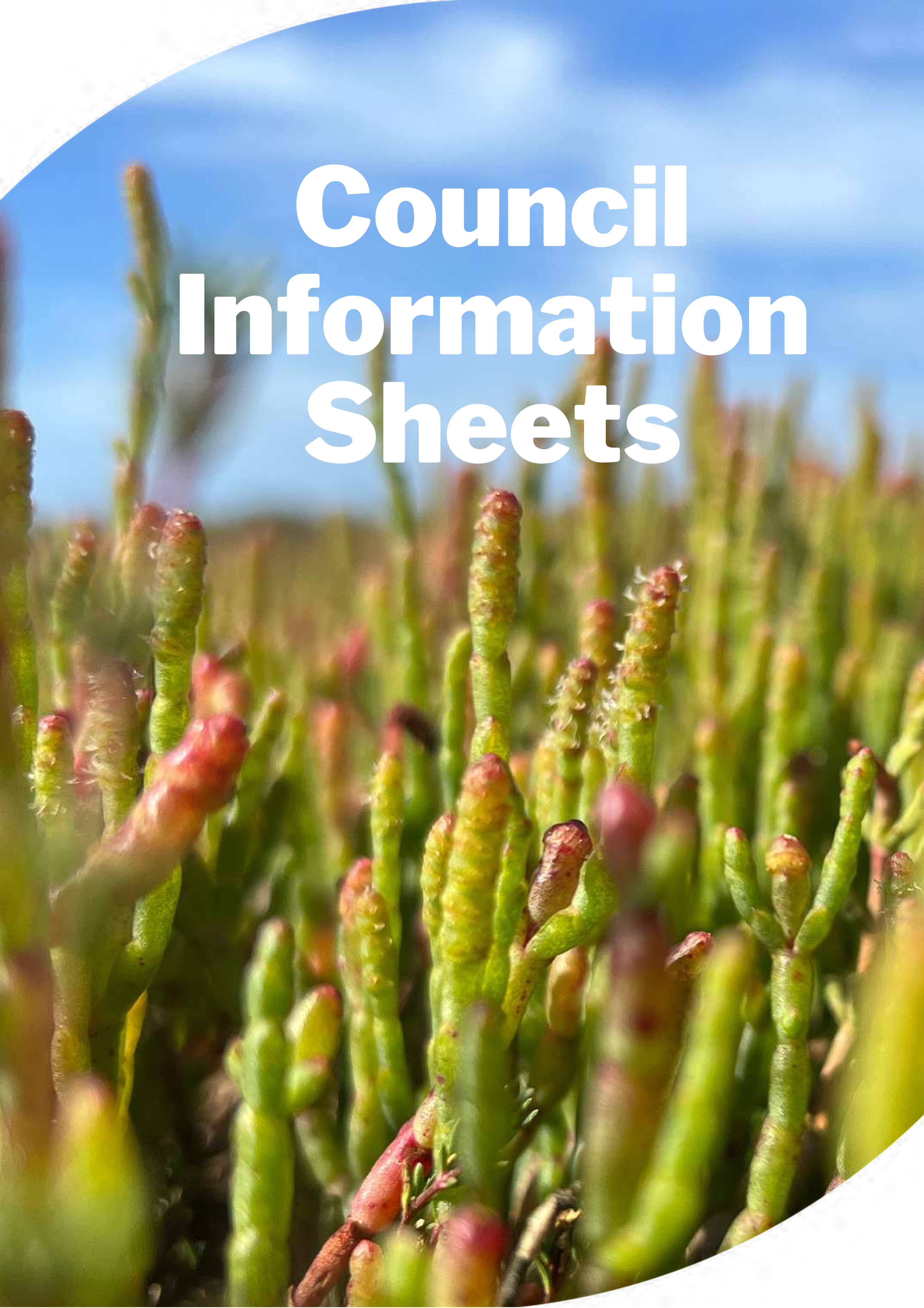
The role of teal carbon ecosystems as a nature climate solution

Teal carbon refers to the carbon trapped in freshwater vegetated areas, such as inland wetlands and farm dams. As their coastal counterparts (i.e., blue carbon), these freshwater ecosystems are efficient in removing carbon dioxide from the atmosphere and storing it in their soils, thereby acting as natural carbon sinks.

However, many teal carbon ecosystems are under threat from human activities, such as land use change, pollution, and water extraction. When these ecosystems are degraded, they release large amounts of CO_2 and methane back into the atmosphere, contributing to climate change. Therefore, it is essential to understand how to manage and restore these ecosystems to maximise their carbon sequestration potential. Research in Victoria and New South Wales has showed how simple management actions such as fencing can reduce by half the carbon emissions from farm dams (Malerba et al. 2022).

Councils with limited blue carbon ecosystems (e.g., Frankston, Bayside, and Kingston) may have better opportunities for carbon mitigation using teal carbon ecosystems. By investing in better management of freshwater wetlands, teal carbon ecosystems can absorb CO_2 from the atmosphere and trap it in wetland sediments for decades and centuries, thus acting as a natural climate solution. Restoring and managing teal carbon sites – such as the Kananook Creek Reserve, the Dandenong Wetlands, or the Yumarrala Wetlands – could provide important opportunities to reduce carbon emissions (e.g., methane) at a local scale.

Council Information Sheets



City of Bayside

Mangroves and saltmarshes are not distributed within the City of Bayside. Therefore, the only opportunity potentially available is if blue carbon ecosystems expand their distribution with sea level rise. In this case, the carbon sequestration value could vary from ~$68,600 to $200,000*. We recommend that opportunities for seagrass and teal carbon are assessed within the council.

Area of blue carbon ecosystems

Mangrove
Previous 0 ha
Current **0 ha**

Saltmarsh
Previous 0 ha
Current **0 ha**

Seagrass
Previous 15 ha
Current **12.6 ha**

Area available for restoration
(considering three management actions)

- Fencing: Mangrove 0 ha; Saltmarsh 0 ha
- Tidal reinstatement: Mangrove 0 ha; Saltmarsh 0 ha
- Managed sea-level retreat: Mangrove 0 ha (2040); Saltmarsh 23.4 ha (2040), 9.2 ha (2070), 14.5 ha (2100)

Ecosystem services of existing ecosystems

	Carbon stocks (tonnes C)	Carbon sequestration (tonnes C y^{-1})	Nitrogen fixation (tonnes N y^{-1})	Commercial fisheries (kg fish y^{-1})	Recreational fisheries (kg fish y^{-1})	Coastal protection (mean N properties)
Mangrove	0	0	0	0	0	0
Saltmarsh	0	0	0	0	0	0
Seagrass	1,017.4	6.3	0.14	51,062.2	3.6	26,101

Ecosystem services of restored ecosystems

		Carbon sequestration	Nitrogen fixation	Commercial fisheries	Recreational fisheries	Coastal protection
Fencing	Mangrove	0	0	0	0	0
Fencing	Saltmarsh	0	0	0	0	0
Tidal reinstatement	Mangrove	0	0	0	0	0
Tidal reinstatement	Saltmarsh	0	0	0	0	0
Managed sea-level retreat 2040	Mangrove	0	0	0	0	0
Managed sea-level retreat 2040	Saltmarsh	46.3	2.65	1,498	3	2,332
Managed sea-level retreat 2070	Saltmarsh	18.3	1.1	590.1	1.2	3,769
Managed sea-level retreat 2100	Saltmarsh	28.8	1.7	930.1	1.9	16,313

Costa MDP, Palacios MM, Macreadie PI, 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.

*Considering a carbon price ranging between $16.1 and $47, and a carbon crediting period of 25 years.

Past and current distribution of coastal wetlands
Scale: 1:40,000
Map projection: GDA 94 VICGRID94

Data sources are fully described in the technical report.

N

0 0.5 1 2 Km

Council limits

Past distribution of mangroves

Current distribution of mangroves

Past distribution of saltmarshes

Current distribution of saltmarshes

Past distribution of seagrasses

Current distribution of seagrasses

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.

Scale: 1:40,000
Map projection: GDA 94 VICGRID94

Data source: Ewers Lewis et al. 2020

0 0.5 1 2 Km

Soil carbon stocks (tonnes per hectare in the top 30 cm of soil)

113.12

2.71

Council limits

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.

Total blue carbon stocks within the coastal wetlands in the region
Scale: 1:36,000
Map projection: GDA 94 VICGRID94

Data sources are fully described in the technical report.

Council limits

N

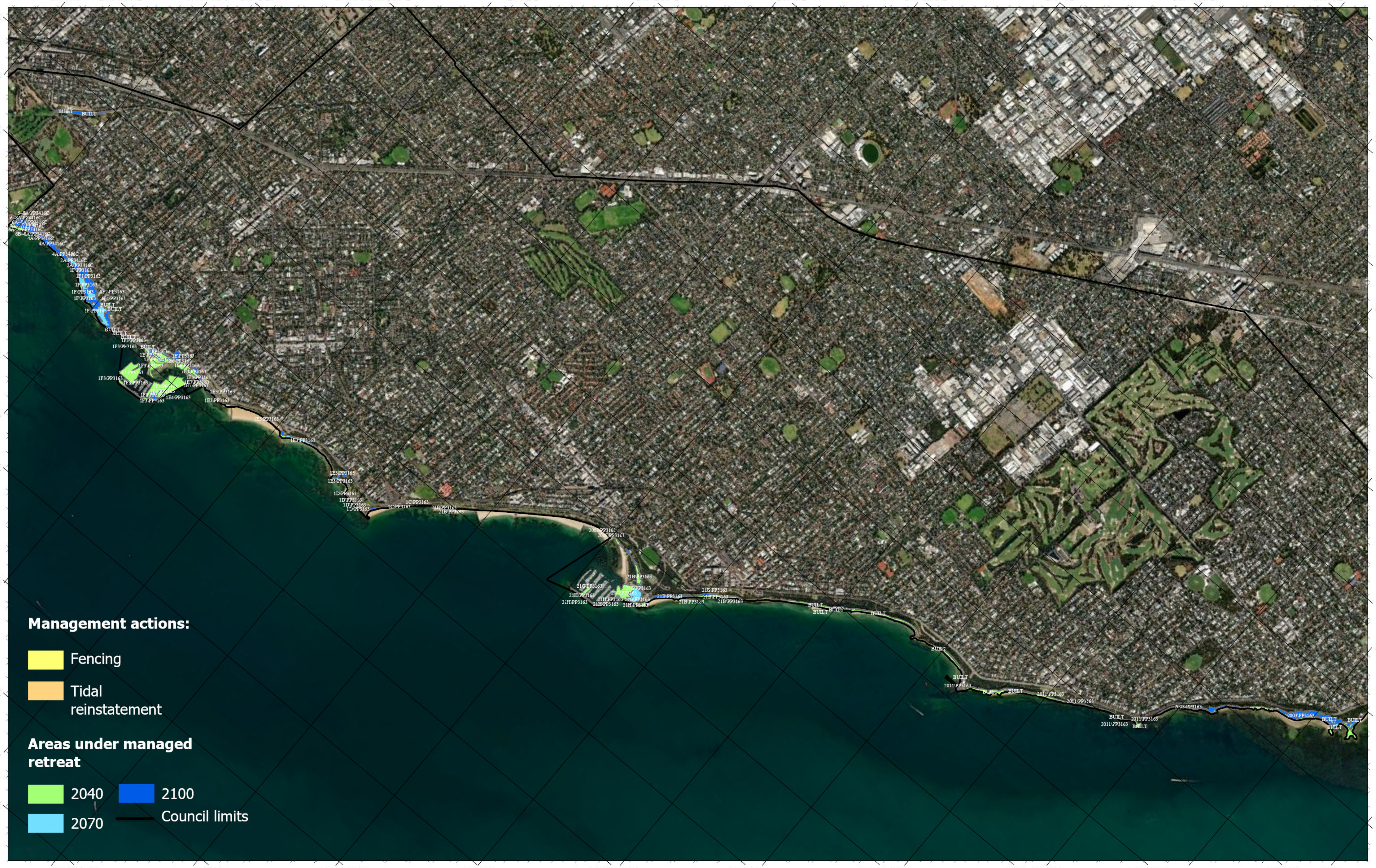
0 0.5 1 2 Km

Soil carbon stocks

Total carbon stocks, in tonnes

Mangroves & Saltmarshes	Seagrasses
< 1,280	< 3,909
< 5,469	< 13,462
< 12,348	< 44,489
< 25,742	< 163,436
< 49,706	< 802,260

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.



Blue Carbon opportunities for different management actions
Scale: 1:30,000
Map projection: GDA 94 VICGRID94

Data sources are fully described in the technical report.

0 0.25 0.5 1 Km

Property boundaries are shown in light grey to help identify landholders and labelled according to the standard parcel identifier (parcel SPI) as per the Victorian Land Use Information System.

Potential carbon value (AUD$) followed by a management action varied from $68,607 to $199,786 for managing sea-level retreat from 2040. Additional opportunities can be achieved from 2070 and 2100. These results are an indicative only, and do not substitute a fully detailed feasibility assessment. Further details are available in the technical report.

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.

City of Kingston

Mangroves and saltmarshes are not distributed within the City of Kingston. Therefore, the only opportunity potentially available is if blue carbon ecosystems expand their distribution with sea level rise. In this case, the carbon sequestration value could vary from ~$950,000 to $2.7 million*. We recommend that opportunities for seagrass and teal carbon are assessed within the council.

Area of blue carbon ecosystems

Ecosystem	Previous	Current
Mangrove	0 ha	**0 ha**
Saltmarsh	0 ha	**0 ha**
Seagrass	78 ha	**0 ha**

Area available for restoration
(considering three management actions)

	Mangrove	Saltmarsh
Fencing	0 ha	0 ha
Tidal reinstatement	0 ha	0 ha
Managed sea-level retreat	0 ha(2040)	323.9 ha (2040); 157.3 ha (2070); 208.7 ha (2100)

Ecosystem services of existing ecosystems

Ecosystem	Carbon stocks (tonnes C)	Carbon sequestration (tonnes C y^{-1})	Nitrogen fixation (tonnes N y^{-1})	Commercial fisheries (kg fish y^{-1})	Recreational fisheries (kg fish y^{-1})	Coastal protection (mean N properties)
Mangrove	0	0	0	0	0	0
Saltmarsh	0	0	0	0	0	0
Seagrass	0	0	0	0	0	0

Ecosystem services of restored ecosystems

		Carbon sequestration (tonnes C y^{-1})	Nitrogen fixation (tonnes N y^{-1})	Commercial fisheries (kg fish y^{-1})	Recreational fisheries (kg fish y^{-1})	Coastal protection (mean N properties)
Fencing	Mangrove	0	0	0	0	0
Fencing	Saltmarsh	0	0	0	0	0
Tidal reinstatement	Mangrove	0	0	0	0	0
Tidal reinstatement	Saltmarsh	0	0	0	0	0
Managed sea-level retreat 2040	Mangrove	0	0	0	0	0
Managed sea-level retreat 2040	Saltmarsh	641.4	16.52	20,731	42.1	4,169
Managed sea-level retreat 2070	Saltmarsh	311.4	8	10,066.8	20.5	3,487
Managed sea-level retreat 2100	Saltmarsh	413.2	10.6	13,354.3	27.1	3,526

Costa MDP, Palacios MM, Macreadie PI, 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.

*Considering a carbon price ranging between $16.1 and $47, and a carbon crediting period of 25 years.

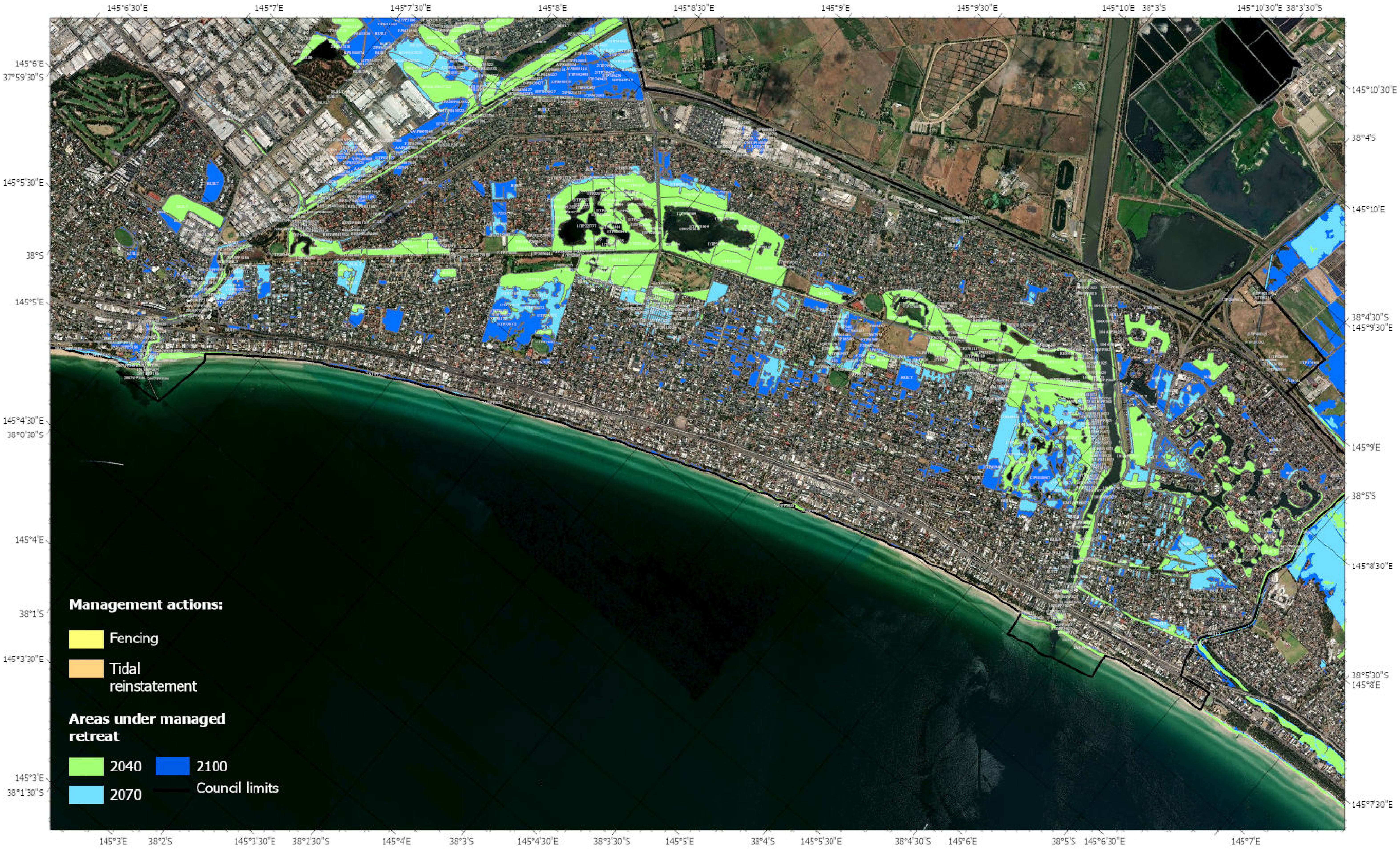
Past and current distribution of coastal wetlands
Scale: 1:50,000
Map projection: GDA 94 VICGRID94

Data sources are fully described in the technical report.

0 0.5 1 2 Km

Council limits	
Past distribution of mangroves	Current distribution of mangroves
Past distribution of saltmarshes	Current distribution of saltmarshes
Past distribution of seagrasses	Current distribution of seagrasses

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.



Blue Carbon opportunities for different management actions
Scale: 1:27,000
Map projection: GDA 94 VICGRID94

Data sources are fully described in the technical report.

Property boundaries are shown in light grey to help identify landholders and labelled according to the standard parcel identifier (parcel SPI) as per the Victorian Land Use Information System.

Potential carbon value (AUD$) followed by a management action varied from $949,784 to $2.7 million for managing sea-level retreat from 2040. Additional opportunities can be achieved from 2070 and 2100. These results are an indicative only, and do not substitute a fully detailed feasibility assessment. Further details are available in the technical report.

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.

City of Frankston

Mangroves and saltmarshes are not distributed within the City of Frankston. Therefore, the only opportunity potentially available is if blue carbon ecosystems expand their distribution with sea level rise. In this case, the carbon sequestration value could vary from ~$660,000 to $1.9 million*. We recommend that opportunities for seagrass and teal carbon are assessed within the council.

Area of blue carbon ecosystems

Ecosystem	Previous	Current
Mangrove	0 ha	**0 ha**
Saltmarsh	0 ha	**0 ha**
Seagrass	0 ha	**0 ha**

Area available for restoration
(considering three management actions)

Management action	Mangrove	Saltmarsh
Fencing	0 ha	0 ha
Tidal reinstatement	0 ha	0 ha
Managed sea-level retreat	0 ha (2040)	224.9 ha (2040); 97.8 ha (2070); 134.9 ha (2100)

Ecosystem services of existing ecosystems

Ecosystem	Carbon stocks (tonnes C)	Carbon sequestration (tonnes C y^{-1})	Nitrogen fixation (tonnes N y^{-1})	Commercial fisheries (kg fish y^{-1})	Recreational fisheries (kg fish y^{-1})	Coastal protection (mean N properties)
Mangrove	0	0	0	0	0	0
Saltmarsh	0	0	0	0	0	0
Seagrass	0	0	0	0	0	0

Ecosystem services of restored ecosystems

Action	Ecosystem	Carbon sequestration (tonnes C y^{-1})	Nitrogen fixation (tonnes N y^{-1})	Commercial fisheries (kg fish y^{-1})	Recreational fisheries (kg fish y^{-1})	Coastal protection (mean N properties)
Fencing	Mangrove	0	0	0	0	0
Fencing	Saltmarsh	0	0	0	0	0
Tidal reinstatement	Mangrove	0	0	0	0	0
Tidal reinstatement	Saltmarsh	0	0	0	0	0
Managed sea-level retreat 2040	Mangrove	0	0	0	0	0
Managed sea-level retreat 2040	Saltmarsh	445.3	11.86	14,395	29.2	2,943
Managed sea-level retreat 2070	Saltmarsh	193.6	5.2	6,257.2	12.7	2,585
Managed sea-level retreat 2100	Saltmarsh	267.1	7	8,632.7	17.5	3,036

Costa MDP, Palacios MM, Macreadie PI, 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.

*Considering a carbon price ranging between $16.1 and $47, and a carbon crediting period of 25 years.

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Blue Carbon opportunities for different management actions
Scale: 1:33,000
Map projection: GDA 94 VICGRID94

Data sources are fully described in the technical report.

N

0 0.25 0.5 1 Km

Property boundaries are shown in light grey to help identify landholders and labelled according to the standard parcel identifier (parcel SPI) as per the Victorian Land Use Information System.

Potential carbon value (AUD$) followed by a management action varied from $659,464 to $1.9 million for managing sea-level retreat from 2040. Additional opportunities can be achieved from 2070 and 2100. These results are an indicative only, and do not substitute a fully detailed feasibility assessment. Further details are available in the technical report.

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.

Shire of Mornington Peninsula

Mangroves and saltmarshes are widely distributed within the Shire of Mornington Peninsula. However, the main restoration opportunity within the council is the managed retreat to sea level rise. In this case, the carbon sequestration value could vary from ~$1.2 to $3.5 million*. Additional restoration opportunities could also be assessed for seagrass and teal carbon.

Area of blue carbon ecosystems

Mangrove
Previous 448 ha
Current **413.1 ha**

Saltmarsh
Previous 420 ha
Current **384.1 ha**

Seagrass
Previous 2,389 ha
Current **4,909.2 ha**

Area available for restoration
(considering three management actions)

Management action	Mangrove	Saltmarsh
Fencing	0 ha	0 ha
Tidal reinstatement	0 ha	0 ha
Managed sea-level retreat	12.8 ha (2040)	399.4 ha (2040); 182.9 ha (2070); 310.4 ha (2100)

Ecosystem services of existing ecosystems

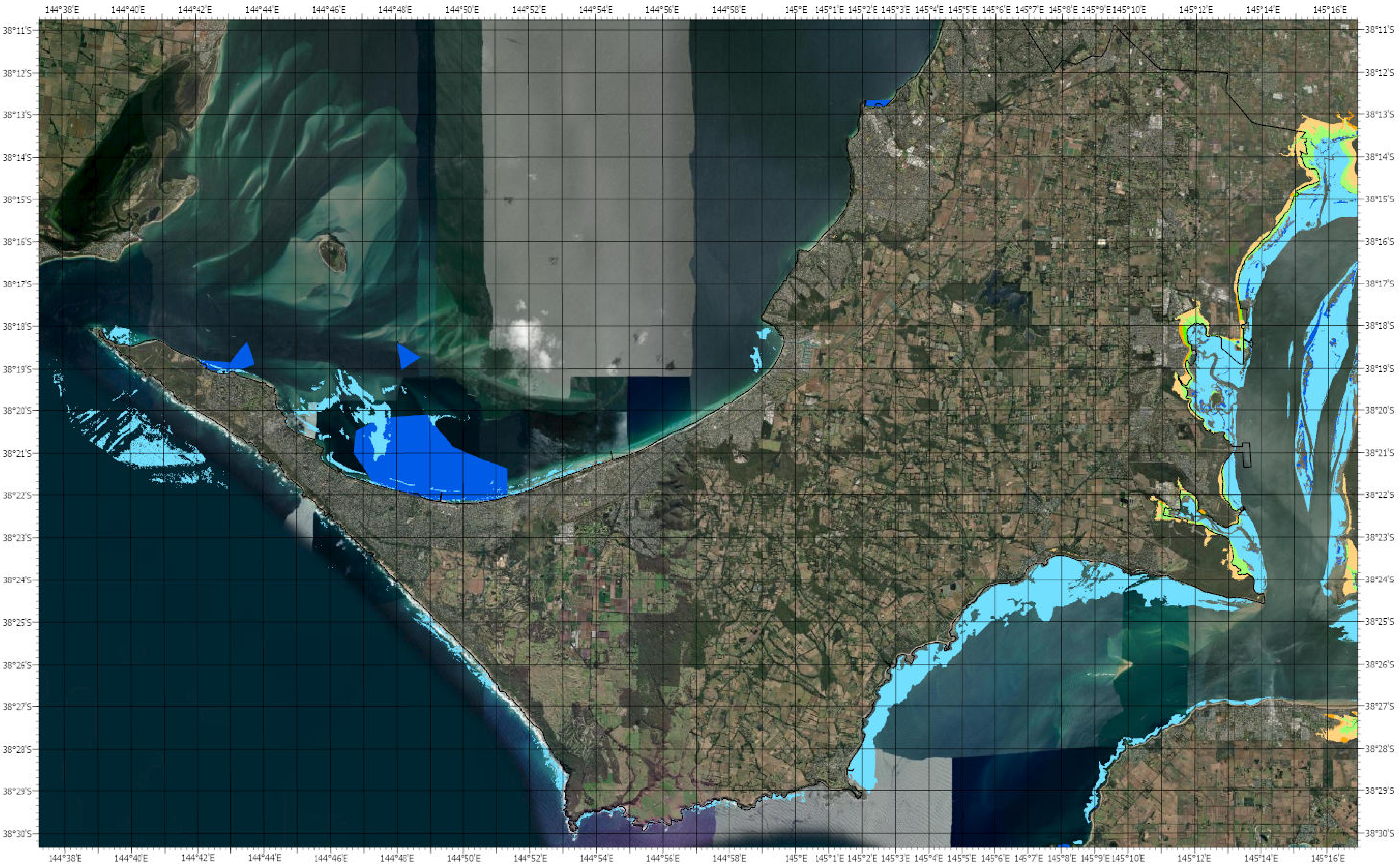
Ecosystem	Carbon stocks (tonnes C)	Carbon sequestration (tonnes C y^{-1})	Nitrogen fixation (tonnes N y^{-1})	Commercial fisheries (kg fish y^{-1})	Recreational fisheries (kg fish y^{-1})	Coastal protection (mean N properties)
Mangrove	90,331	719	5.4	109,471	215	191
Saltmarsh	111,505	253	44.2	24,580	50	183
Seagrass	397,648	2,455	49.1	19.9 million	944.5	4,876

Ecosystem services of restored ecosystems

Action	Ecosystem	Carbon sequestration	Nitrogen fixation	Commercial fisheries	Recreational fisheries	Coastal protection
Fencing	Mangrove	0	0	0	0	0
Fencing	Saltmarsh	0	0	0	0	0
Tidal reinstatement	Mangrove	0	0	0	0	0
Tidal reinstatement	Saltmarsh	0	0	0	0	0
Managed sea-level retreat 2040	Mangrove	34.5	0.2	3,384	6.6	474
Managed sea-level retreat 2040	Saltmarsh	791	45.8	25,564	51.9	555
Managed sea-level retreat 2070	Saltmarsh	362	21	11,702	23.8	504
Managed sea-level retreat 2100	Saltmarsh	614.5	35.7	19,863	40.3	524

*Considering a carbon price ranging between $16.1 and $47, and a carbon crediting period of 25 years.

Costa MDP, Palacios MM, Macreadie PI, 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.



Past and current distribution of coastal wetlands
Scale: 1:150,000
Map projection: GDA 94 VICGRID94

Data sources are fully described in the technical report.

N

0 1.5 3 6 Km

Council limits

Past distribution of mangroves

Current distribution of mangroves

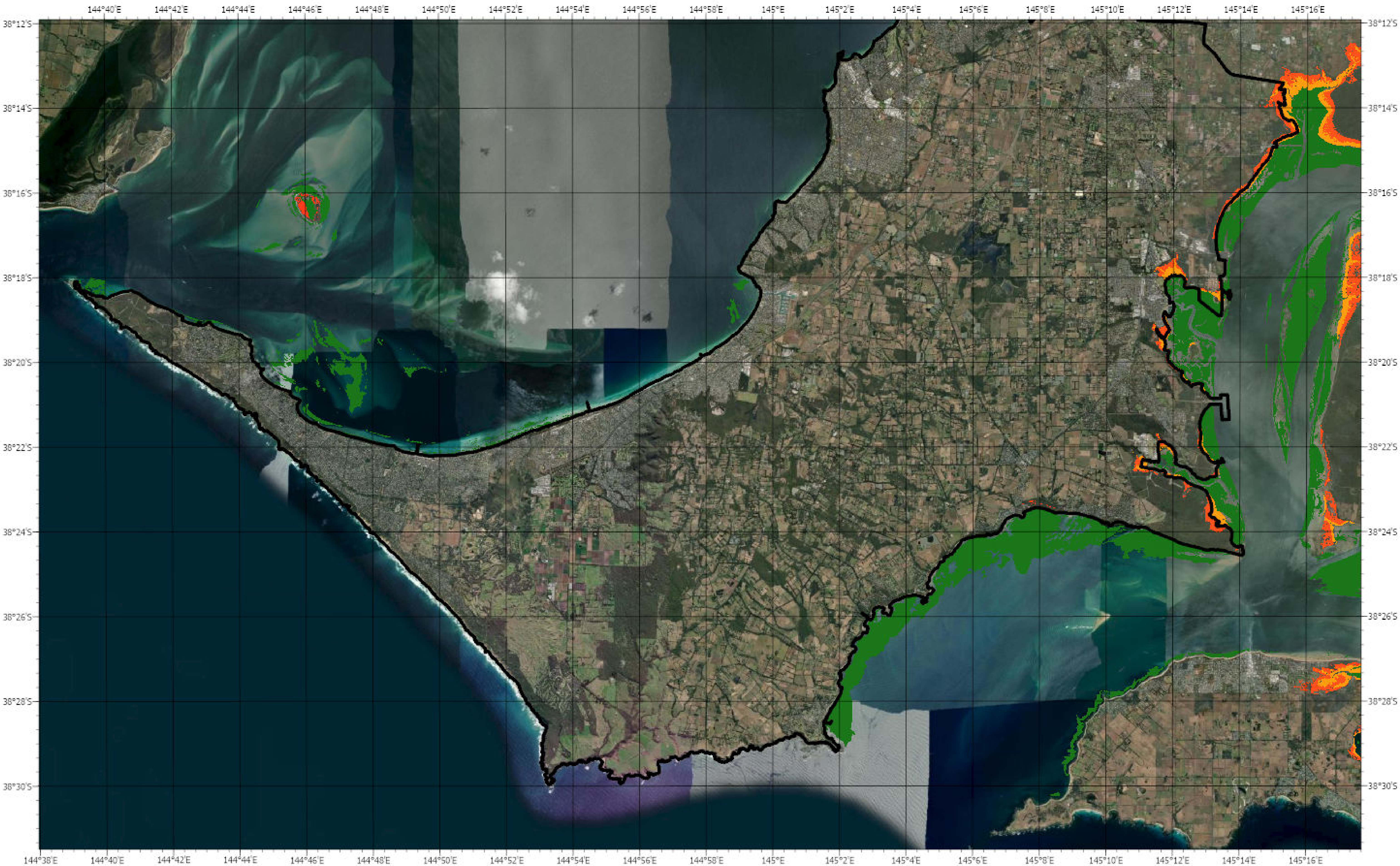
Past distribution of saltmarshes

Current distribution of saltmarshes

Past distribution of seagrasses

Current distribution of seagrasses

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.



Scale: 1:150,000
Map projection: GDA 94 VICGRID94

Data source: Ewers Lewis et al. 2020

N

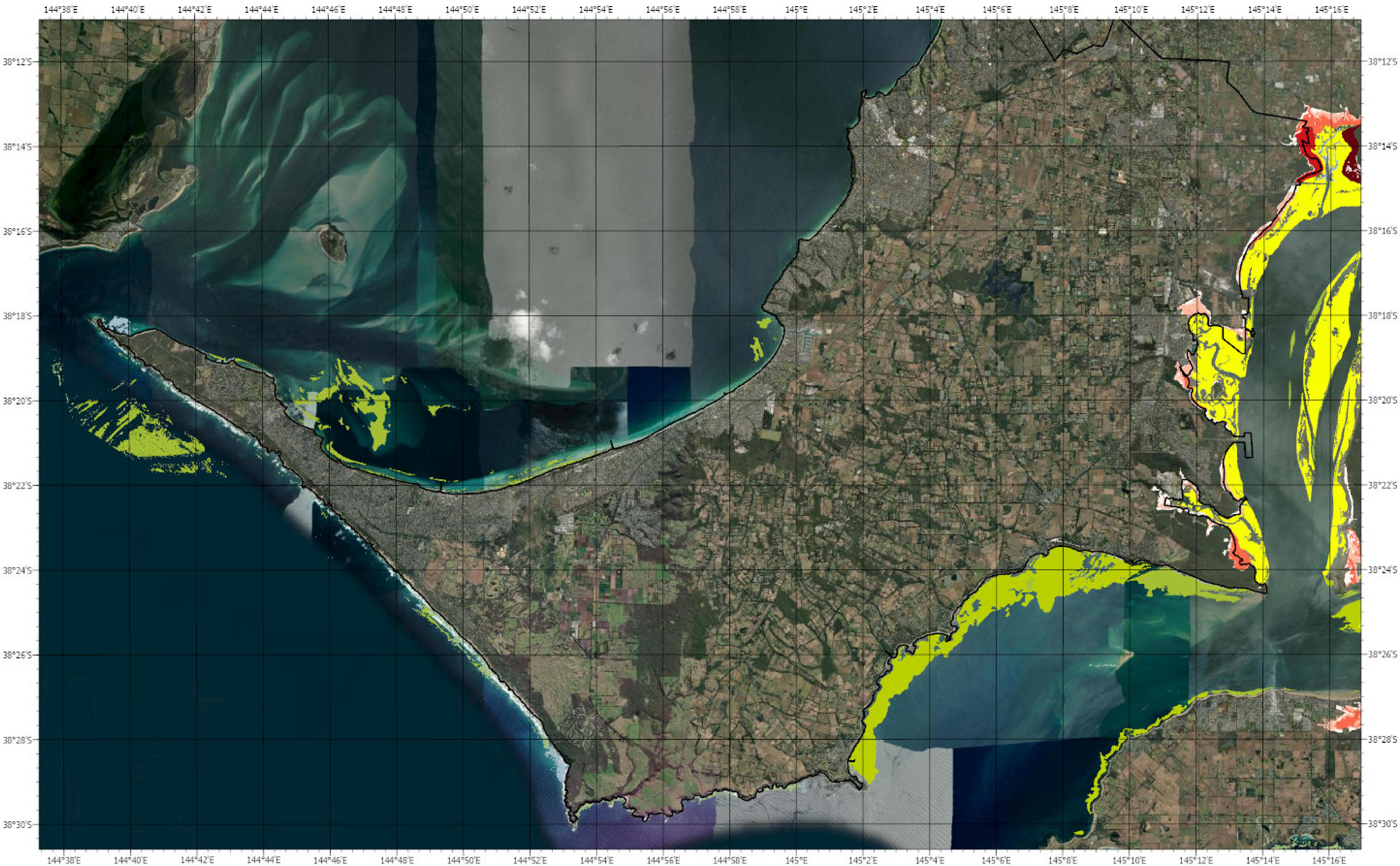
0 1.75 3.5 7 Km

Soil carbon stocks (tonnes per hectare in the top 30 cm of soil)

113.12

2.71 — Council limits

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.



Total blue carbon stocks within the coastal wetlands in the region
Scale: 1:150,000
Map projection: GDA 94 VICGRID94

Data sources are fully described in the technical report.

Council limits

N

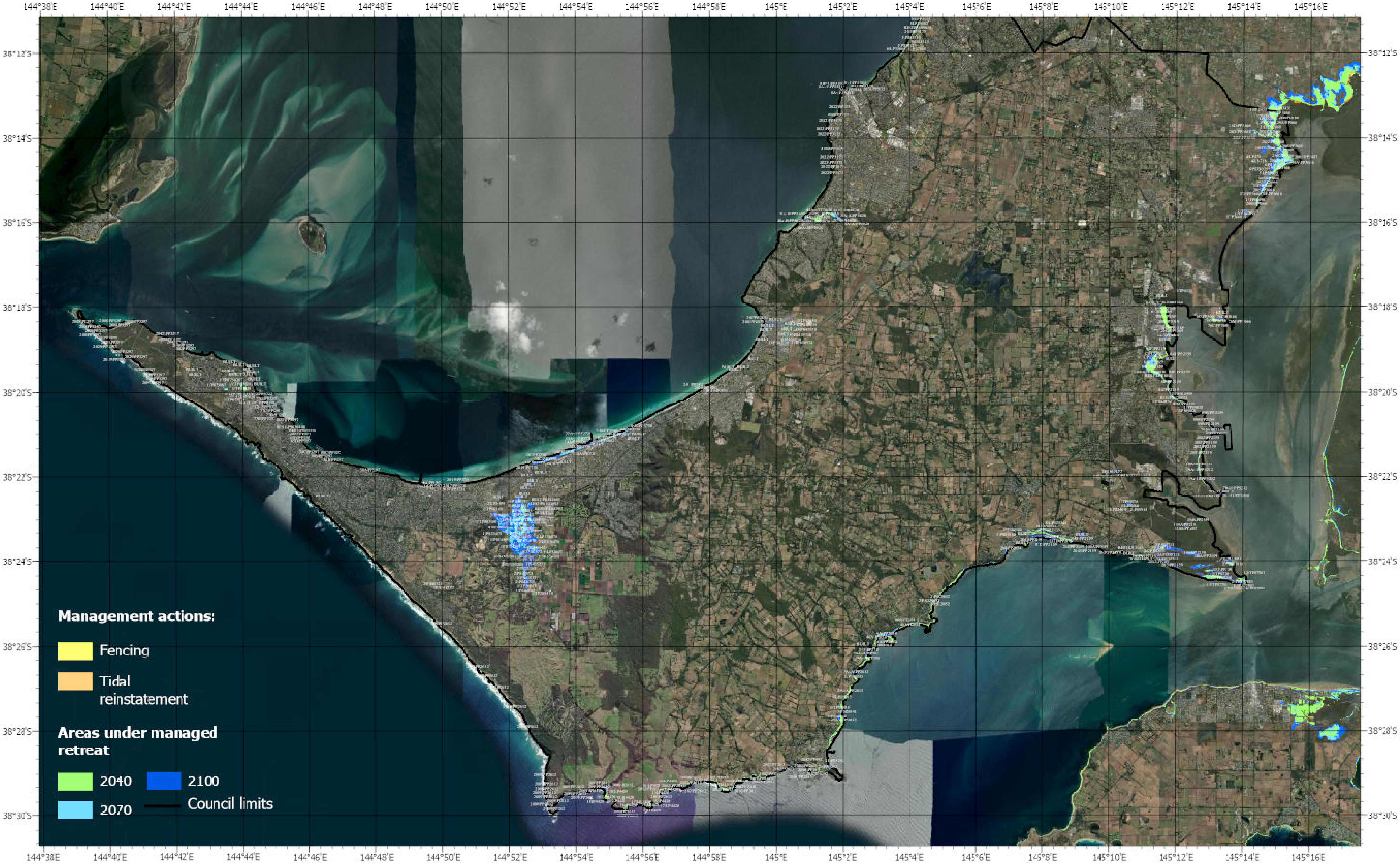
0 2 4 8 Km

Soil carbon stocks

Total carbon stocks, in tonnes

Mangroves & Saltmarshes	Seagrasses
< 1,280	< 3,909
< 5,469	< 13,462
< 12,348	< 44,489
< 25,742	< 163,436
< 49,706	< 802,260

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.



Blue Carbon opportunities for different management actions
Scale: 1:150,000
Map projection: GDA 94 VICGRID94

Data sources are fully described in the technical report.

N

0 1.25 2.5 5 Km

Property boundaries are shown in light grey to help identify landholders and labelled according to the standard parcel identifier (parcel SPI) as per the Victorian Land Use Information System.

Potential carbon value (AUD$) followed by a management action varied from $1.2 million to $3.5 million for managing sea-level retreat from 2040. Additional opportunities can be achieved from 2070 and 2100. These results are an indicative only, and do not substitute a fully detailed feasibility assessment. Further details are available in the technical report.

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.

City of Casey

Mangroves and saltmarshes are widely distributed within the City of Casey, with fencing, tidal reinstatement, and managed retreat available to restore these ecosystems. If restored, carbon sequestration could potentially vary from $1.5 to $12.7 million*. Additional opportunities could also be assessed for seagrass and teal carbon restoration.

Area of blue carbon ecosystems

Mangrove
Previous 711.3 ha
Current **803.7 ha**

Saltmarsh
Previous 810.3 ha
Current **718.5 ha**

Seagrass
Previous 2,551 ha
Current **1,577 ha**

Area available for restoration
(considering three management actions)

Management action	Mangrove	Saltmarsh
Fencing	0.2 ha	36.9 ha
Tidal reinstatement	1.2 ha	141 ha
Managed sea-level retreat	5.6 ha (2040)	1,486 ha (2040); 503 ha (2070); 1,097 ha (2100)

Ecosystem services of existing ecosystems

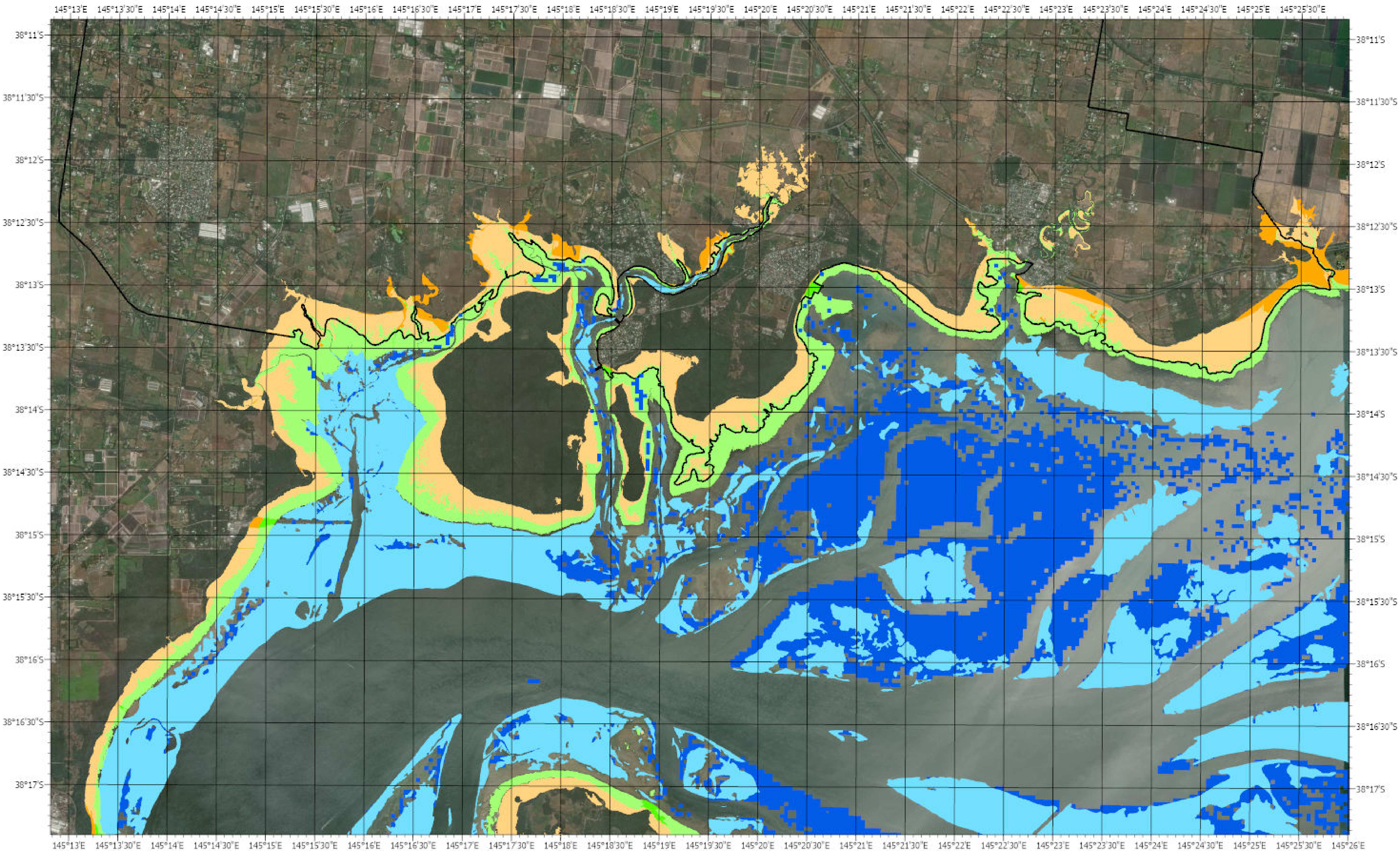
	Carbon stocks (tonnes C)	Carbon sequestration (tonnes C y^{-1})	Nitrogen fixation (tonnes N y^{-1})	Commercial fisheries (kg fish y^{-1})	Recreational fisheries (kg fish y^{-1})	Coastal protection (mean N properties)
Mangrove	175,745	1,398	10.4	212,983	417	307
Saltmarsh	208,616	474	82.6	45,987	93.4	167
Seagrass	127,778	789	15.8	6.4 million	1,181	1,544

Ecosystem services of restored ecosystems

Action	Ecosystem	Carbon sequestration (tonnes C y^{-1})	Nitrogen fixation (tonnes N y^{-1})	Commercial fisheries (kg fish y^{-1})	Recreational fisheries (kg fish y^{-1})	Coastal protection (mean N properties)
Fencing	Mangrove	0.5	0.002	48.4	0.1	110
Fencing	Saltmarsh	73.1	4.2	2,361	4.8	148
Tidal reinstatement	Mangrove	3.3	0.02	319	0.6	261
Tidal reinstatement	Saltmarsh	280	16.2	9,036	18.4	278
Managed sea-level retreat 2040	Mangrove	15.1	0.1	1,478	2.9	361
Managed sea-level retreat 2040	Saltmarsh	2,942	171	95,081	193	215
Managed sea-level retreat 2070	Saltmarsh	996	57.9	32,196	65.4	138
Managed sea-level retreat 2100	Saltmarsh	2,172	126	70,193	142.6	188

Costa MDP, Palacios MM, Macreadie PI, 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.

*Considering a carbon price ranging between $16.1 and $47, and a carbon crediting period of 25 years.



Past and current distribution of coastal wetlands
Scale: 1:50,000
Map projection: GDA 94 VICGRID94

Data sources are fully described in the technical report.

N

0 0.5 1 2 Km

Council limits

Past distribution of mangroves

Current distribution of mangroves

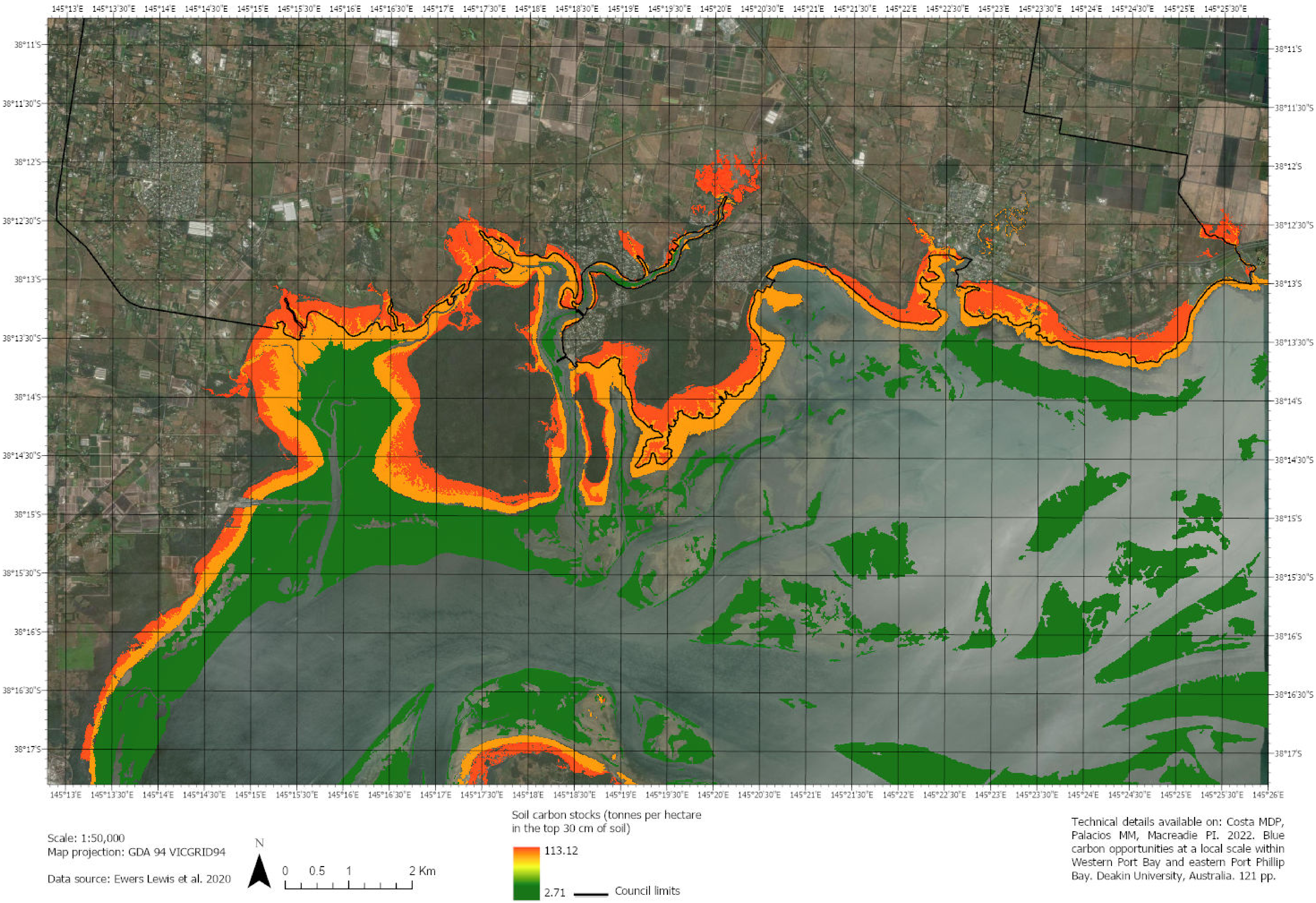
Past distribution of saltmarshes

Current distribution of saltmarshes

Past distribution of seagrasses

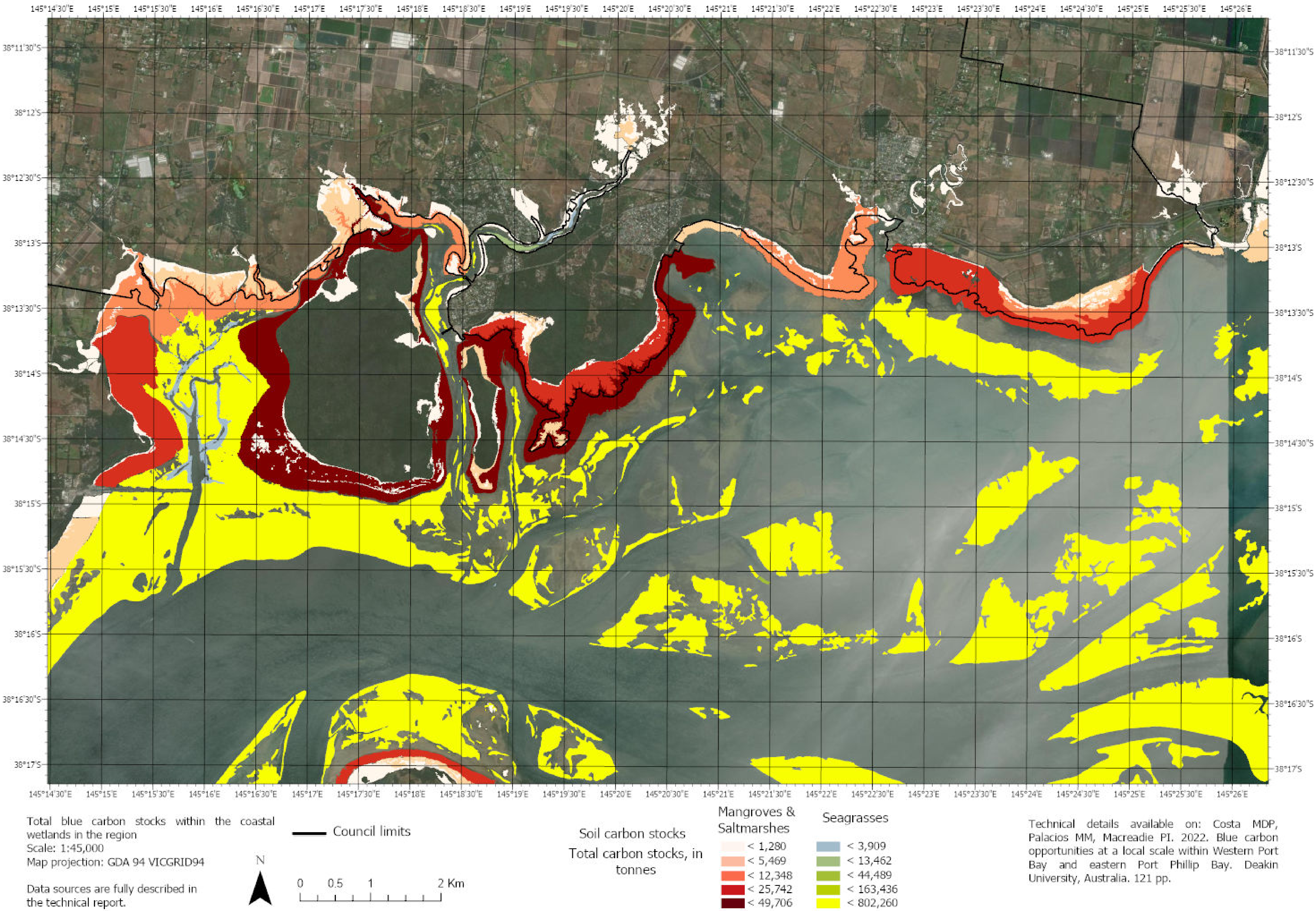
Current distribution of seagrasses

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.



Scale: 1:50,000
Map projection: GDA 94 VICGRID94
Data source: Ewers Lewis et al. 2020

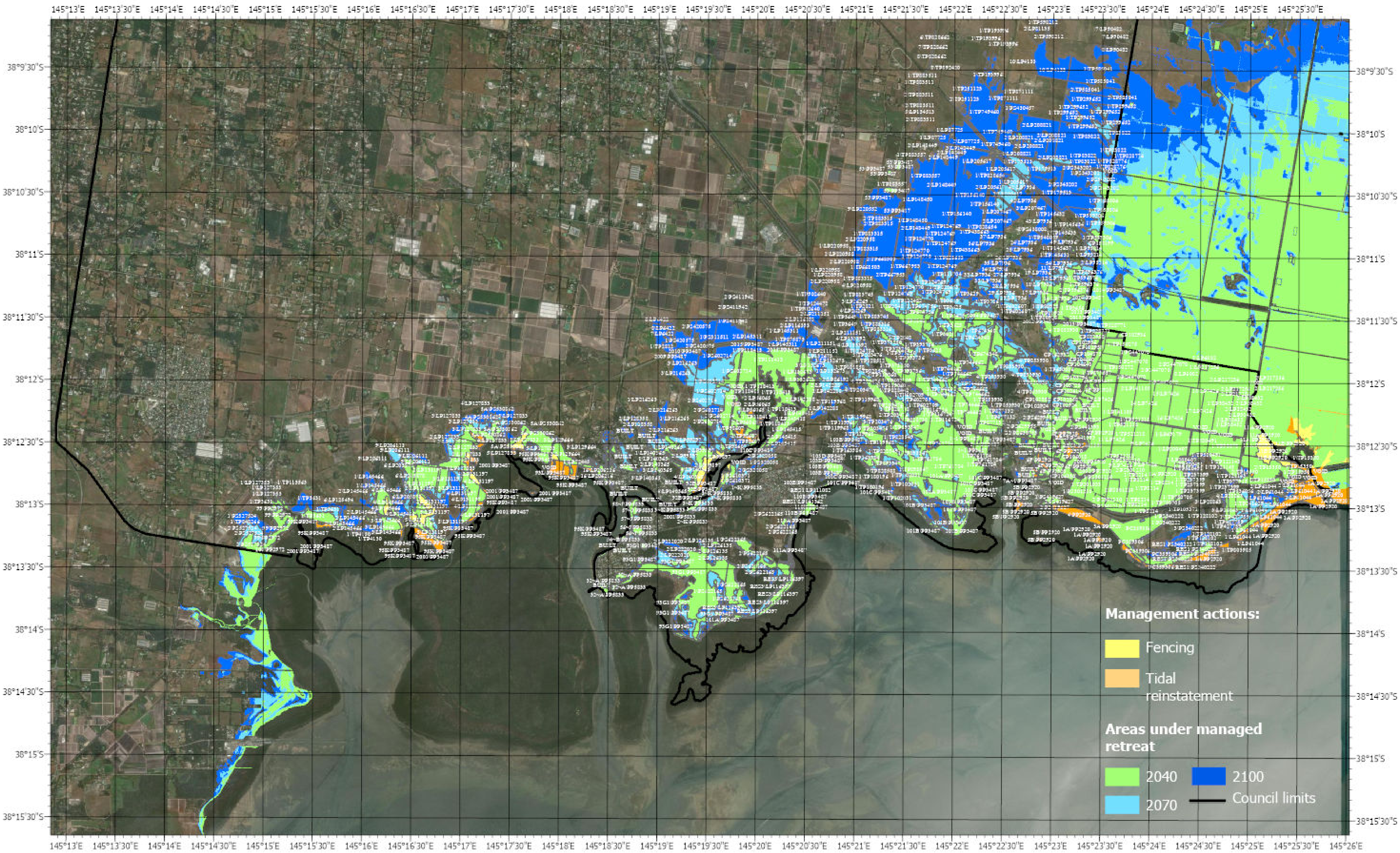
Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.



Total blue carbon stocks within the coastal wetlands in the region
Scale: 1:45,000
Map projection: GDA 94 VICGRID94

Data sources are fully described in the technical report.

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.



Blue Carbon opportunities for different management actions
Scale: 1:50,000
Map projection: GDA 94 VICGRID94

Data sources are fully described in the technical report.

N

0 0.5 1 2 Km

Property boundaries are shown in light grey to help identify landholders and labelled according to the standard parcel identifier (parcel SPI) as per the Victorian Land Use Information System.

Potential carbon value (AUD$) followed by a management action varied from \$108,196 to \$317,165 for fencing, \$418,798 to \$1.2 million for tidal reinstatement, and \$4.3 million to \$12.7 million for managing sea-level retreat from 2040. Additional opportunities can be achieved from 2070 and 2100. These results are an indicative only, and do not substitute a fully detailed feasibility assessment. Further details are available in the technical report.

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.

Cardinia Shire

Mangroves and saltmarshes are widely distributed within the Cardinia Shire, with fencing, tidal reinstatement, and managed retreat available to restore these ecosystems. If restored, carbon sequestration could potentially vary from $51,000 to $30.2 million*. Additional opportunities could also be assessed for seagrass and teal carbon restoration.

Area of blue carbon ecosystems

Ecosystem	Previous	Current
Mangrove	45 ha	**44.4 ha**
Saltmarsh	219.2 ha	**132.4 ha**
Seagrass	1,811 ha	**270 ha**

Area available for restoration
(considering three management actions)

	Mangrove	Saltmarsh
Fencing	0 ha	17.4 ha
Tidal reinstatement	0.6 ha	183 ha
Managed sea-level retreat	0.1 ha (2040)	3,540 ha (2040); 1,313 ha (2070); 1,407 ha (2100)

Ecosystem services of existing ecosystems

Ecosystem	Carbon stocks (tonnes C)	Carbon sequestration (tonnes C y^{-1})	Nitrogen fixation (tonnes N y^{-1})	Commercial fisheries (kg fish y^{-1})	Recreational fisheries (kg fish y^{-1})	Coastal protection (mean N properties)
Mangrove	9,711	77.3	0.6	11,769	23.1	23
Saltmarsh	38,434	87.4	15.2	8,472	17.2	21
Seagrass	21,889	135.1	2.7	1.1 million	525.2	8,833

Ecosystem services of restored ecosystems

Action	Ecosystem	Carbon sequestration	Nitrogen fixation	Commercial fisheries	Recreational fisheries	Coastal protection
Fencing	Mangrove	0	0	0	0	0
Fencing	Saltmarsh	34.5	2.0	1,114	2.3	30
Tidal reinstatement	Mangrove	1.6	0.001	158.5	0.3	20
Tidal reinstatement	Saltmarsh	362.4	21.1	11,714.6	23.8	17
Managed retreat 2040	Mangrove	0.4	0.002	37.3	0.1	21
Managed retreat 2040	Saltmarsh	7,009	407.1	226,568	460.2	74
Managed retreat 2070	Saltmarsh	2,600	151	84,058.2	170.7	73
Managed retreat 2100	Saltmarsh	2,785	161.8	90,019.4	182.9	100

Costa MDP, Palacios MM, Macreadie PI, 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.

*Considering a carbon price ranging between $16.1 and $47, and a carbon crediting period of 25 years.

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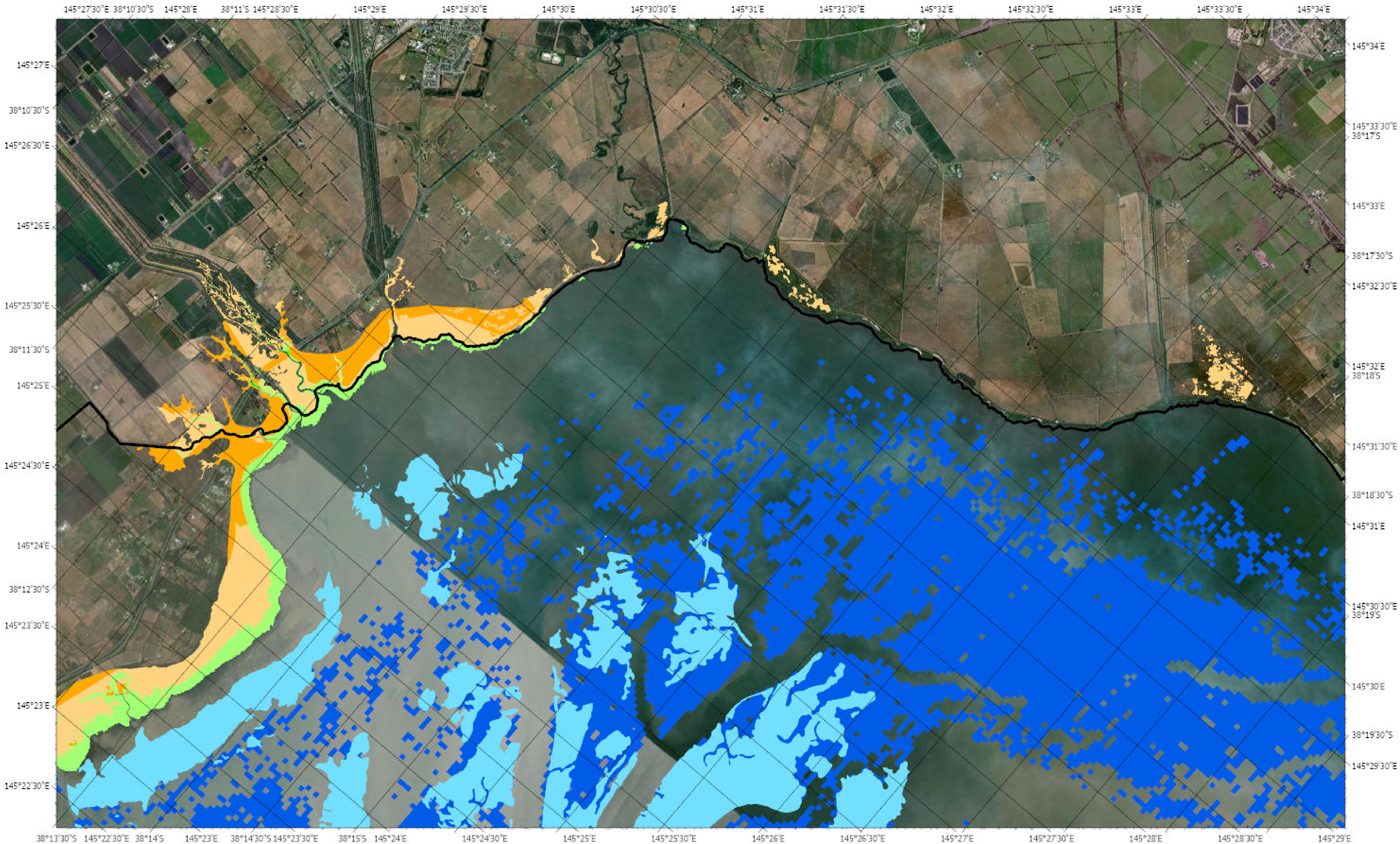


Past and current distribution of coastal wetlands
Scale: 1:40,000
Map projection: GDA 94 VICGRID94

Data sources are fully described in the technical report.

N

0 0.5 1 2 Km

Council limits

Past distribution of mangroves

Current distribution of mangroves

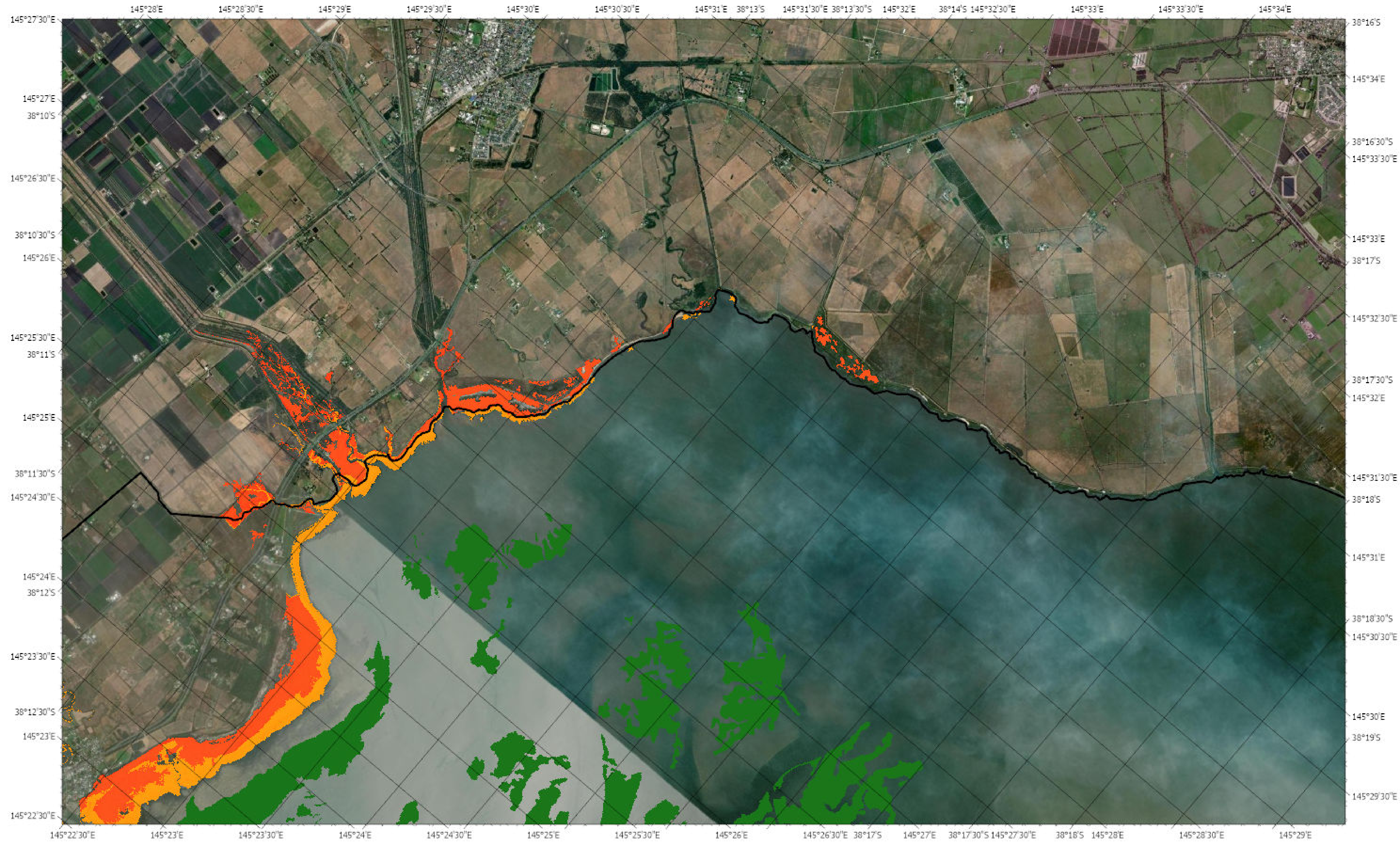
Past distribution of saltmarshes

Current distribution of saltmarshes

Past distribution of seagrasses

Current distribution of seagrasses

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.



Scale: 1:40,000
Map projection: GDA 94 VICGRID94

Data source: Ewers Lewis et al. 2020

Soil carbon stocks (tonnes per hectare in the top 30 cm of soil)

113.12

2.71

Council limits

0 0.5 1 2 Km

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.

Total blue carbon stocks within the coastal wetlands in the region
Scale: 1:40,000
Map projection: GDA 94 VICGRID94

Data sources are fully described in the technical report.

Council limits

N

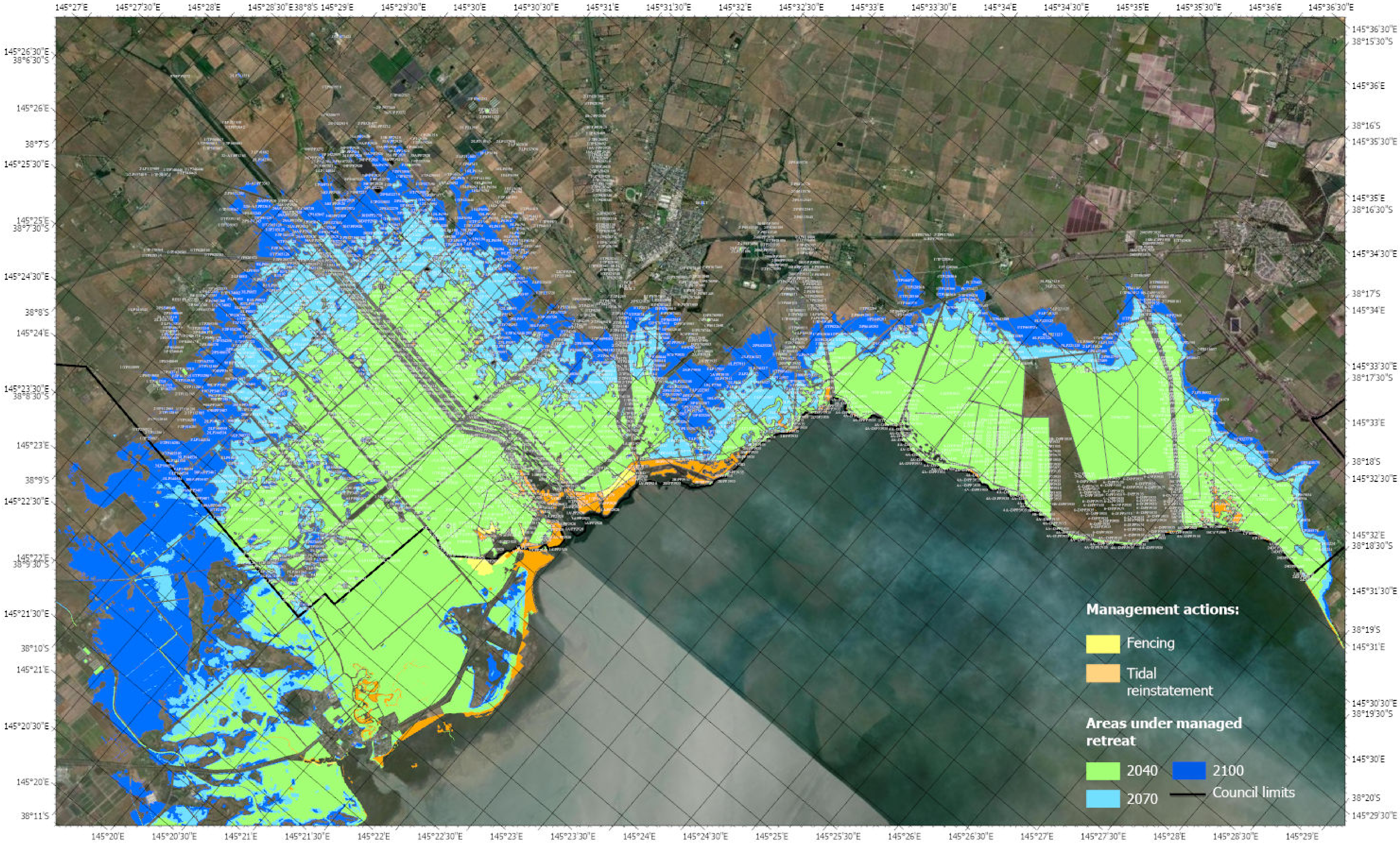
0 0.5 1 2 Km

Soil carbon stocks

Total carbon stocks, in tonnes

Mangroves & Saltmarshes	Seagrasses
< 1,280	< 3,909
< 5,469	< 13,462
< 12,348	< 44,489
< 25,742	< 163,436
< 49,706	< 802,260

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.



Blue Carbon opportunities for different management actions
Scale: 1:57,000
Map projection: GDA 94 VICGRID94

Data sources are fully described in the technical report.

N
0 0.5 1 2 Km

Property boundaries are shown in light grey to help identify landholders and labelled according to the standard parcel identifier (parcel SPI) as per the Victorian Land Use Information System.

Potential carbon value (AUD$) followed by a management action varied from $51,044 to $148,643 for fencing, $539,072 to $1.5 million for tidal reinstatement, and $10.3 million to $30.2 million for managing sea-level retreat from 2040. Additional opportunities can be achieved from 2070 and 2100. These results are an indicative only, and do not substitute a fully detailed feasibility assessment. Further details are available in the technical report.

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.

Bass Coast Shire

Mangroves and saltmarshes are widely distributed within the Bass Coast Shire, with fencing, tidal reinstatement, and managed retreat available to restore these ecosystems. If restored, carbon sequestration could potentially vary from $778,000 to $21.7 million*. Additional opportunities could also be assessed for seagrass and teal carbon restoration.

Area of blue carbon ecosystems

Ecosystem	Previous	Current
Mangrove	245.4 ha	**194.3 ha**
Saltmarsh	804.4 ha	**520.3 ha**
Seagrass	1,253 ha	**4,282 ha**

Area available for restoration
(considering three management actions)

Management action	Mangrove	Saltmarsh
Fencing	1.8 ha	263 ha
Tidal reinstatement	0.01 ha	115 ha
Managed sea-level retreat	12.7 ha (2040)	2,524 ha (2040); 550 ha (2070); 537 ha (2100)

Ecosystem services of existing ecosystems

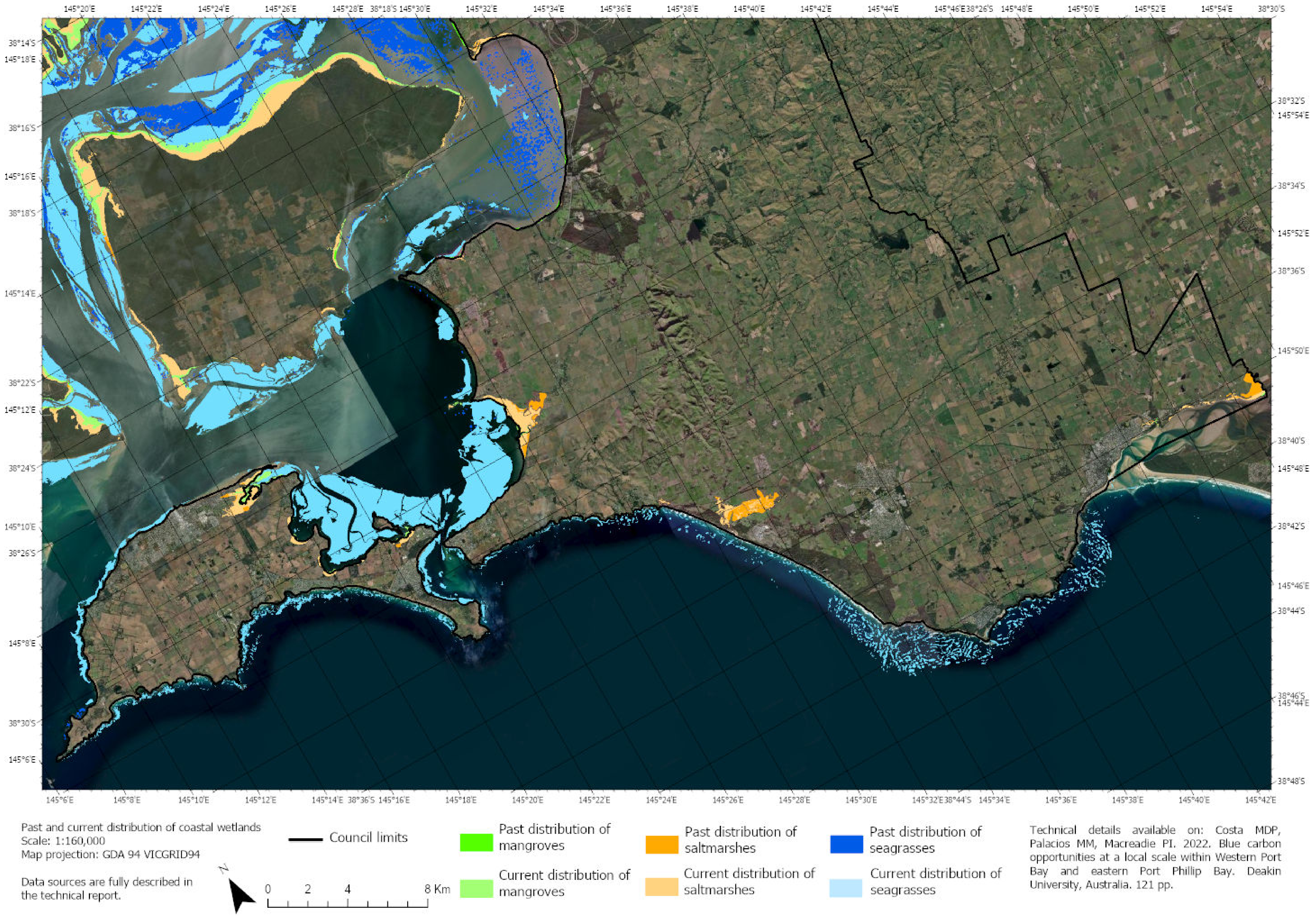
Ecosystem	Carbon stocks (tonnes C)	Carbon sequestration (tonnes C y^{-1})	Nitrogen fixation (tonnes N y^{-1})	Commercial fisheries (kg fish y^{-1})	Recreational fisheries (kg fish y^{-1})	Coastal protection (mean N properties)
Mangrove	42,491	338.1	2.5	51,495	101	267
Saltmarsh	151,049	343	59.8	33,297	67.6	117
Seagrass	346,818	2,141	42.8	17.4 million	363.4	1,355

Ecosystem services of restored ecosystems

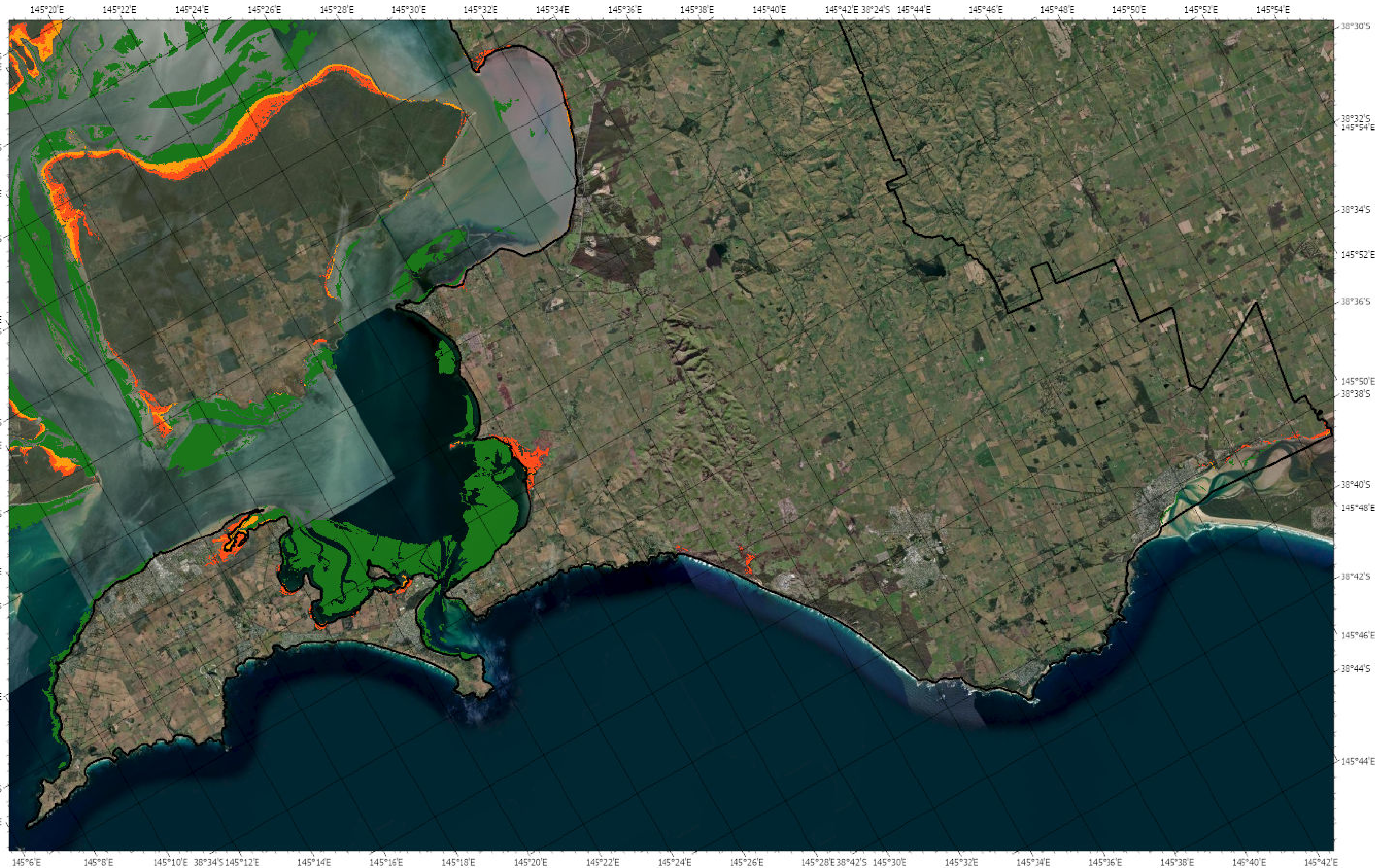
Action	Ecosystem	Carbon sequestration	Nitrogen fixation	Commercial fisheries	Recreational fisheries	Coastal protection
Fencing	Mangrove	4.9	0.023	476.6	0.9	217
Fencing	Saltmarsh	520.5	30.2	16,826	34.2	68
Tidal reinstatement	Mangrove	0.031	0.0001	3.1	0.06	54
Tidal reinstatement	Saltmarsh	227.4	13.2	7,350	14.9	30
Managed retreat 2040	Mangrove	34.3	0.2	3,363	6.6	434
Managed retreat 2040	Saltmarsh	4,998	290.3	161,554	328	381
Managed retreat 2070	Saltmarsh	1,090	63.3	35,228	71.6	429
Managed retreat 2100	Saltmarsh	1,063	61.7	34,348	69.8	516

Costa MDP, Palacios MM, Macreadie PI, 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.

*Considering a carbon price ranging between $16.1 and $47, and a carbon crediting period of 25 years.



Past and current distribution of coastal wetlands
Scale: 1:160,000
Map projection: GDA 94 VICGRID94
Data sources are fully described in the technical report.
Council limits
Past distribution of mangroves
Current distribution of mangroves
Past distribution of saltmarshes
Current distribution of saltmarshes
Past distribution of seagrasses
Current distribution of seagrasses
N
0 2 4 8 Km
Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.



Scale: 1:160,000

Map projection: GDA 94 VICGRID94

Data source: Ewers Lewis et al. 2020

Soil carbon stocks (tonnes per hectare in the top 30 cm of soil)

113.12

2.71

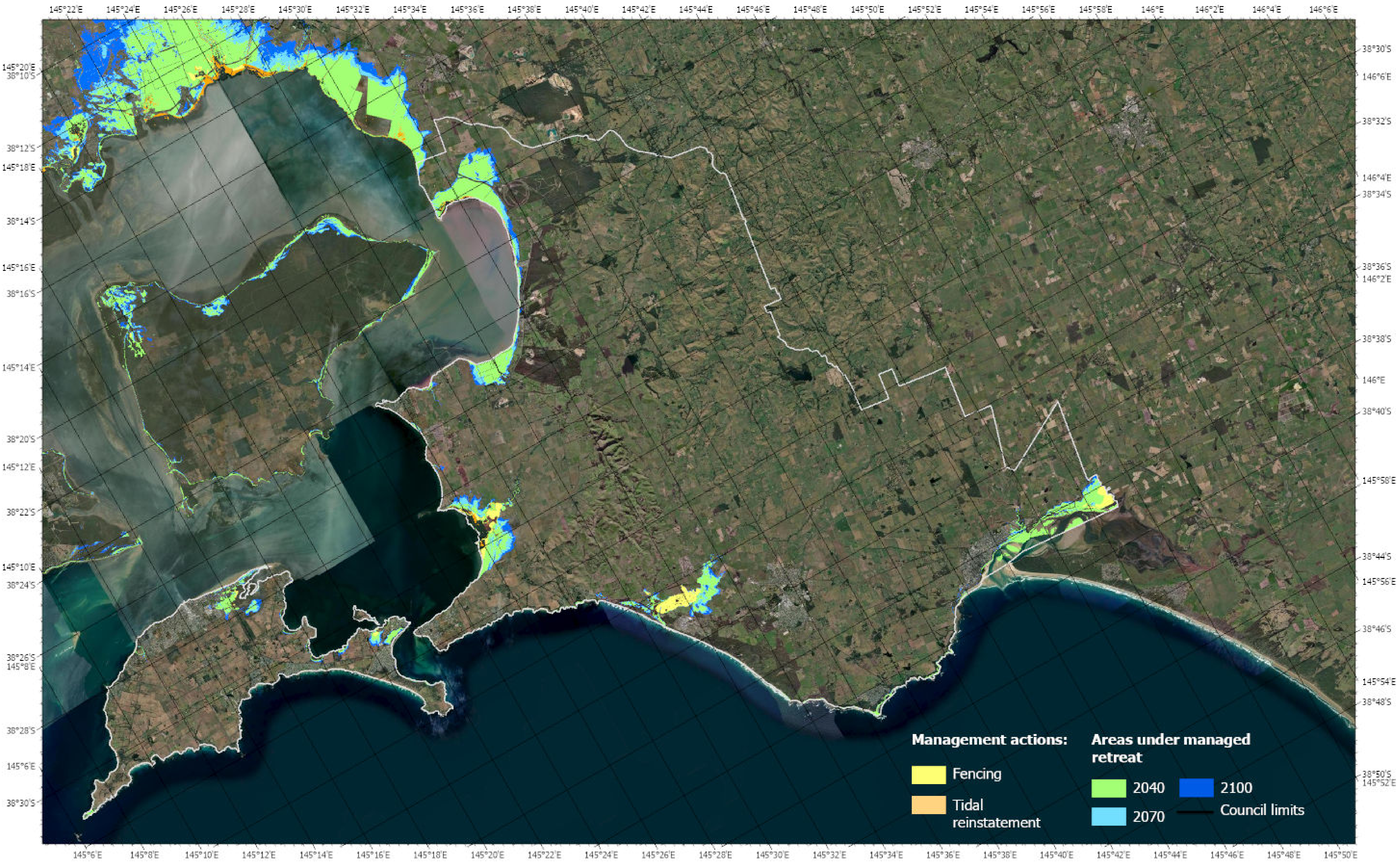
Council limits

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.

Total blue carbon stocks within the coastal wetlands in the region
Scale: 1:160,000
Map projection: GDA 94 VICGRID94

Data sources are fully described in the technical report.

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.



Blue Carbon opportunities for different management actions
Scale: 1:200,000
Map projection: GDA 94 VICGRID94

Data sources are fully described in the technical report.

N

0 1.75 3.5 7 Km

Property boundaries are shown in light grey to help identify landholders and labelled according to the standard parcel identifier (parcel SPI) as per the Victorian Land Use Information System.

Potential carbon value (AUD$) followed by a management action varied from $778,035 to $2.2 million for fencing, $336,790 to $980,739 for tidal reinstatement, and $7.4 million to $21.7 million for managing sea-level retreat from 2040. Additional opportunities can be achieved from 2070 and 2100. These results are an indicative only, and do not substitute a fully detailed feasibility assessment. Further details are available in the technical report.

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.

French Island

Mangroves and saltmarshes are widely distributed within French Island, with fencing and managed retreat available to restore these ecosystems. If restored, carbon sequestration could potentially vary from $6,780 to $4.4 million*. Additional opportunities could also be assessed for seagrass restoration.

Area of blue carbon ecosystems

Ecosystem	Previous	Current
Mangrove	481.6 ha	**474.2 ha**
Saltmarsh	1,014.5 ha	**991 ha**
Seagrass	2,607 ha	**3,894 ha**

Area available for restoration
(considering three management actions)

Management action	Mangrove	Saltmarsh
Fencing	0 ha	2.3 ha
Tidal reinstatement	0 ha	0 ha
Managed sea-level retreat	2.4 ha (2040)	518 ha (2040); 201 ha (2070); 226 ha (2100)

Ecosystem services of existing ecosystems

Ecosystem	Carbon stocks (tonnes C)	Carbon sequestration (tonnes C y^{-1})	Nitrogen fixation (tonnes N y^{-1})	Commercial fisheries (kg fish y^{-1})	Recreational fisheries (kg fish y^{-1})	Coastal protection (mean N properties)
Mangrove	103,685	825.1	6.2	125,655	247	6
Saltmarsh	287,717	654.1	114	63,423	129	6
Seagrass	315,381	1,947	38.9	15.8 million	1,189	3,391

Ecosystem services of restored ecosystems

Management action	Ecosystem	Carbon sequestration (tonnes C y^{-1})	Nitrogen fixation (tonnes N y^{-1})	Commercial fisheries (kg fish y^{-1})	Recreational fisheries (kg fish y^{-1})	Coastal protection (mean N properties)
Fencing	Mangrove	0	0	0	0	0
Fencing	Saltmarsh	4.6	0.3	148.2	0.3	8
Tidal reinstatement	Mangrove	0	0	0	0	0
Tidal reinstatement	Saltmarsh	0	0	0	0	0
Managed sea-level retreat 2040	Mangrove	6.5	0.03	641	1.3	9
Managed sea-level retreat 2040	Saltmarsh	1,026	59.6	33,154	67.3	10
Managed sea-level retreat 2070	Saltmarsh	398.6	23.1	12,885	26.2	14
Managed sea-level retreat 2100	Saltmarsh	447	26	14,442	29.3	14

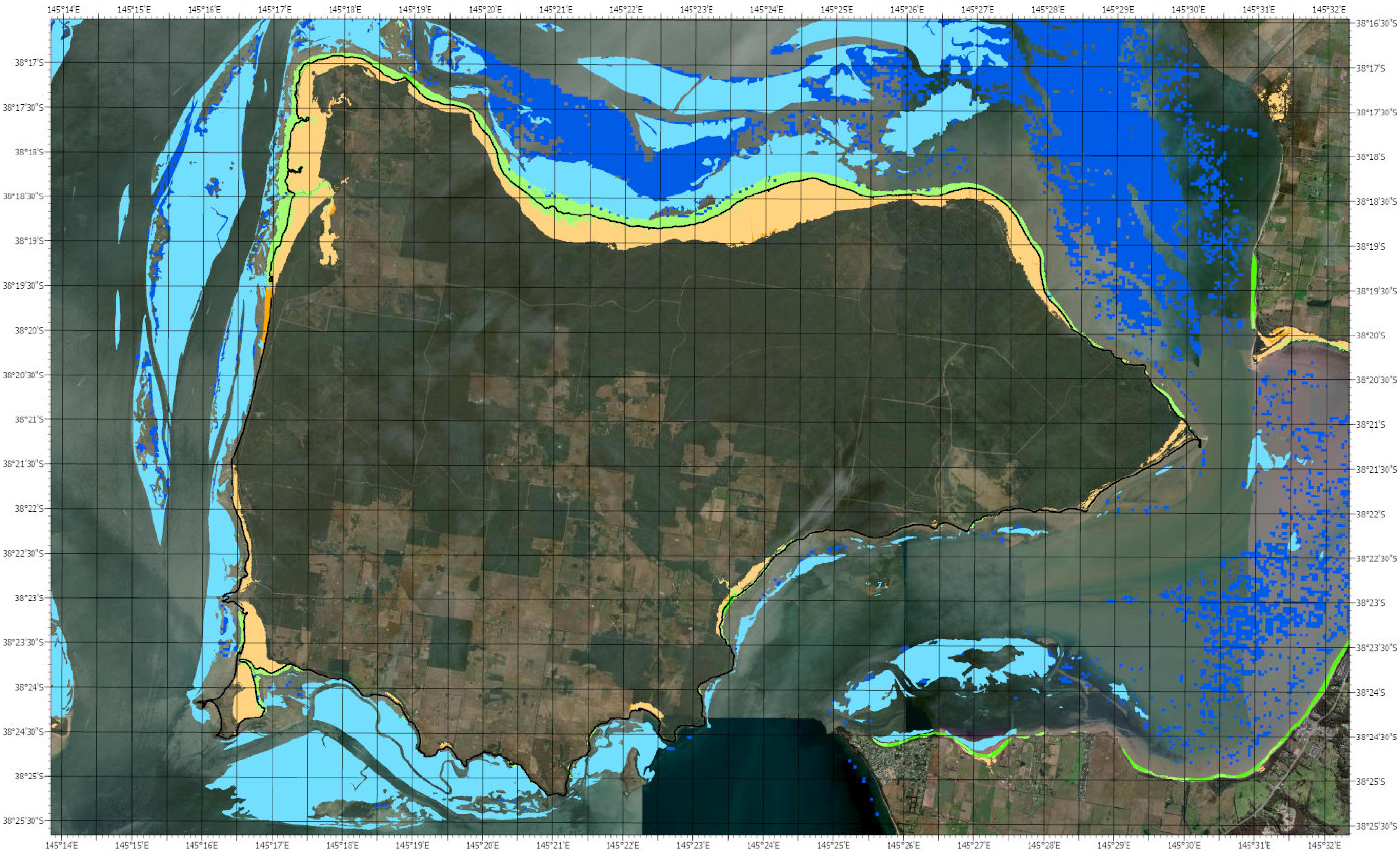
Costa MDP, Palacios MM, Macreadie PI, 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.

*Considering a carbon price ranging between $16.1 and $47, and a carbon crediting period of 25 years.

Blue Carbon Lab

DEAKIN UNIVERSITY

WESTERN PORT BIOSPHERE



Past and current distribution of coastal wetlands
Scale: 1:70,000
Map projection: GDA 94 VICGRID94

Data sources are fully described in the technical report.

N

0 0.75 1.5 3 Km

Council limits

Past distribution of mangroves

Current distribution of mangroves

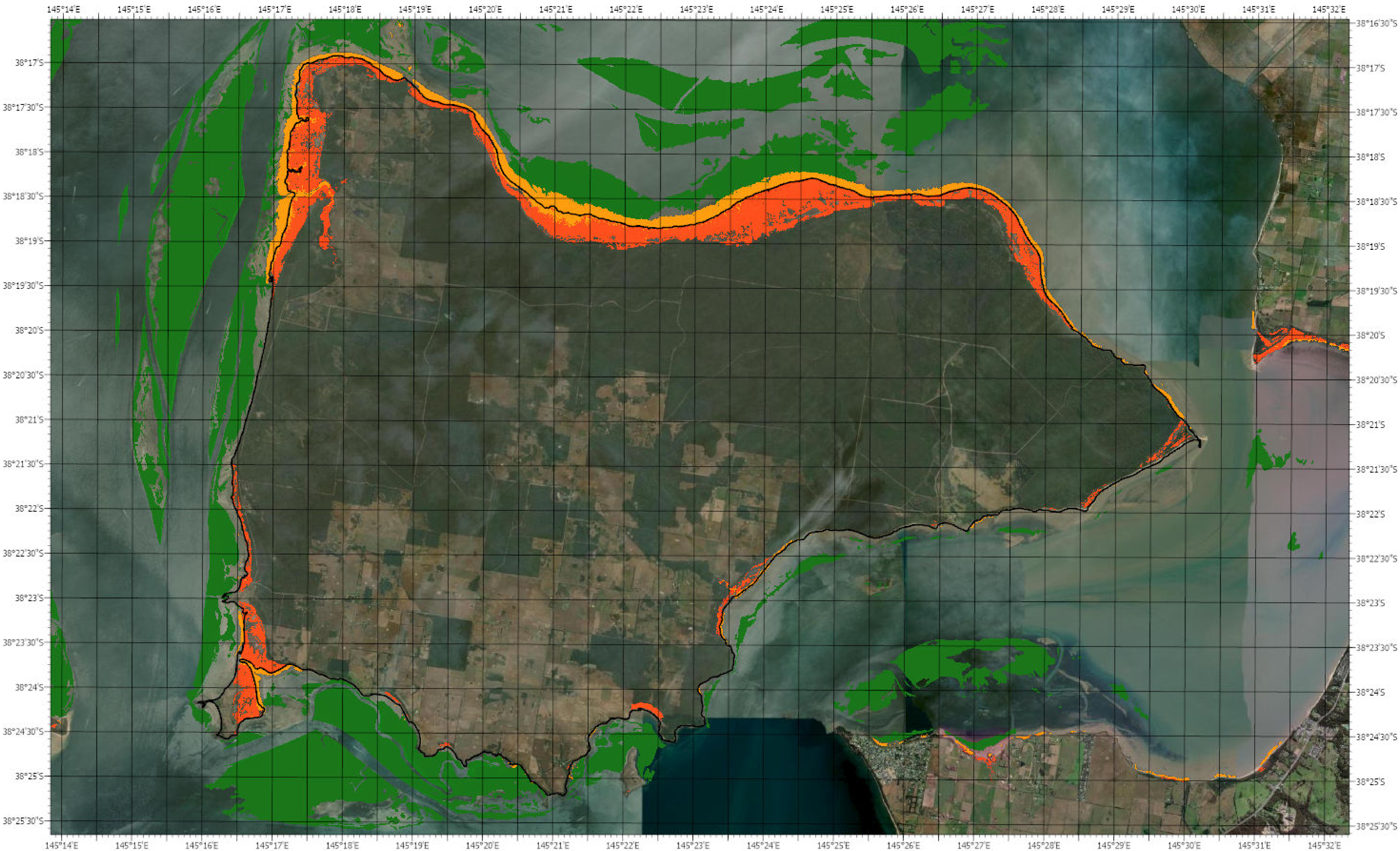
Past distribution of saltmarshes

Current distribution of saltmarshes

Past distribution of seagrasses

Current distribution of seagrasses

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.



Scale: 1:70,000
Map projection: GDA 94 VICGRID94
Data source: Ewers Lewis et al. 2020

N

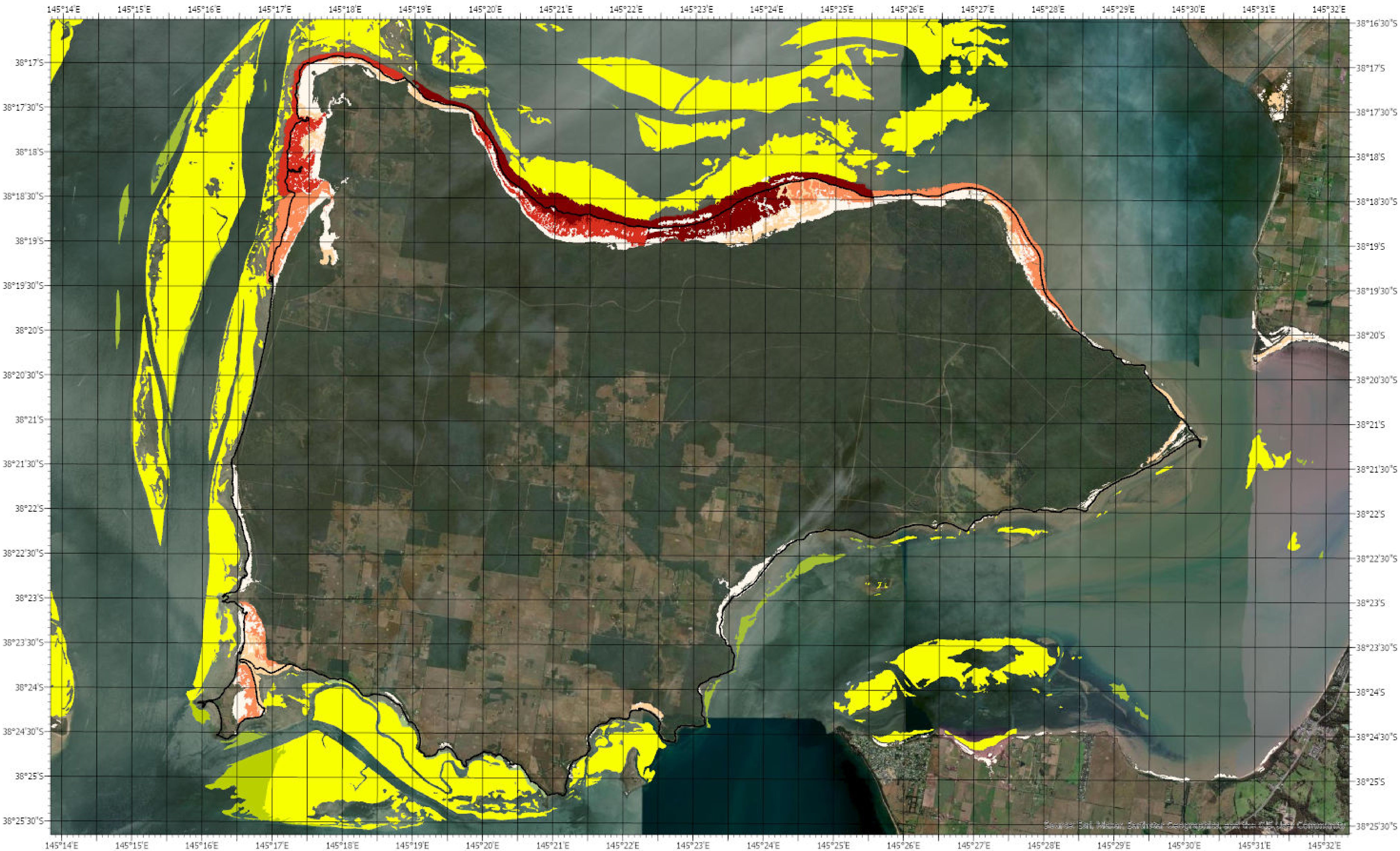
0 0.75 1.5 3 Km

Soil carbon stocks (tonnes per hectare in the top 30 cm of soil)

113.12

2.71 Council limits

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.



Total blue carbon stocks within the coastal wetlands in the region
Scale: 1:70,000
Map projection: GDA 94 VICGRID94

Data sources are fully described in the technical report.

N

0 0.75 1.5 3 Km

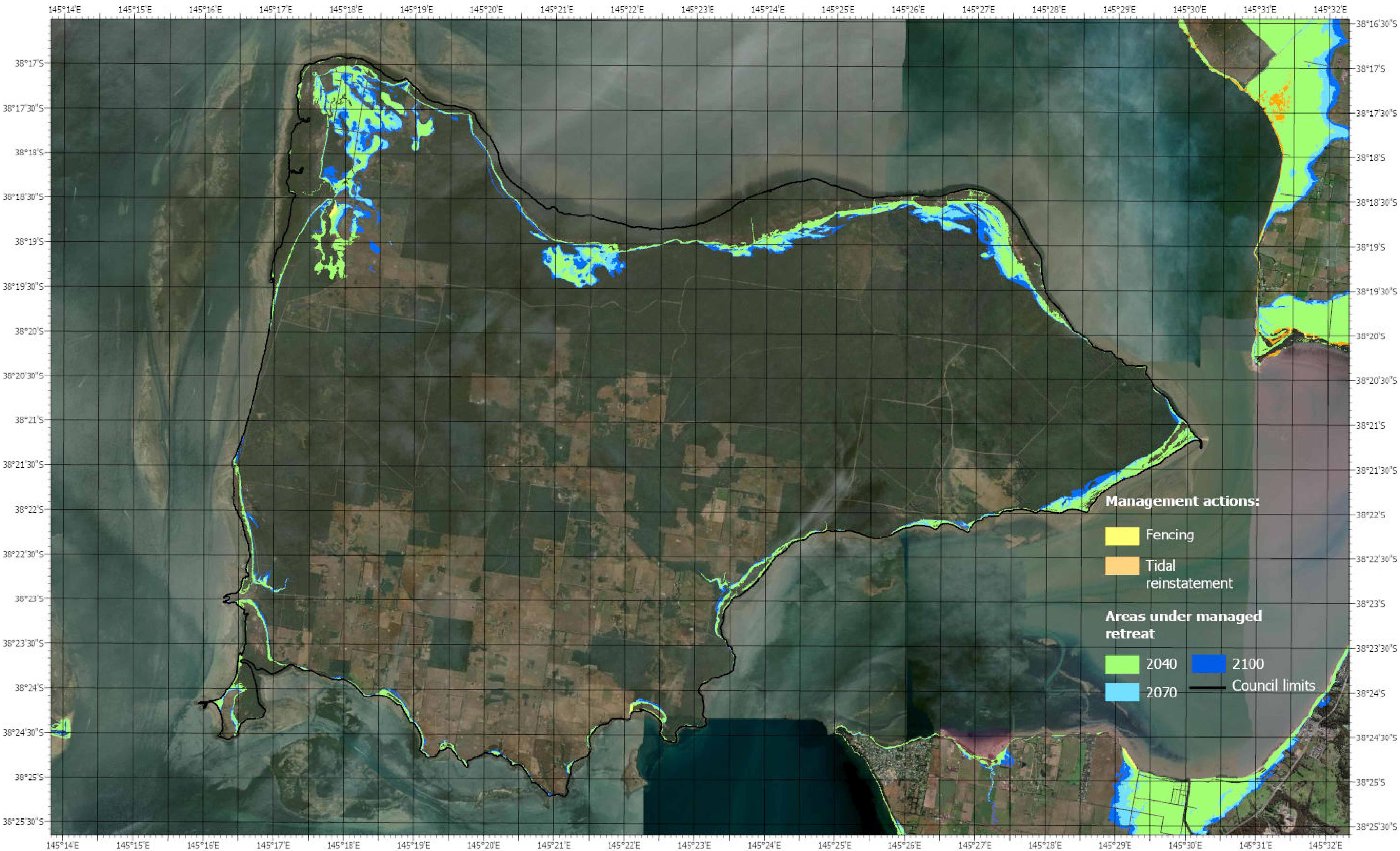
Council limits

Soil carbon stocks

Total carbon stocks, in tonnes

Mangroves & Saltmarshes	Seagrasses
< 1,280	< 3,909
< 5,469	< 13,462
< 12,348	< 44,489
< 25,742	< 163,436
< 49,706	< 802,260

Technical details available on: Costa MDP, Palacios MM, Macreadie PI. 2022. Blue carbon opportunities at a local scale within Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.



Blue Carbon opportunities for different management actions
Scale: 1:70,000
Map projection: GDA 94 VICGRID94

Data sources are fully described in the technical report.

N

0 0.5 1 2 Km

Property boundaries are shown in light grey to help identify landholders and labelled according to the standard parcel identifier (parcel SPI) as per the Victorian Land Use Information System.

Potential carbon value (AUD$) followed by a management action varied from $6,782 to $19,759 for fencing and $1.5 to $4.4 million for managing sea-level retreat from 2040. Additional opportunities can be achieved from 2070 and 2100. These results are an indicative only, and do not substitute a fully detailed feasibility assessment. Further details are available in the technical report.

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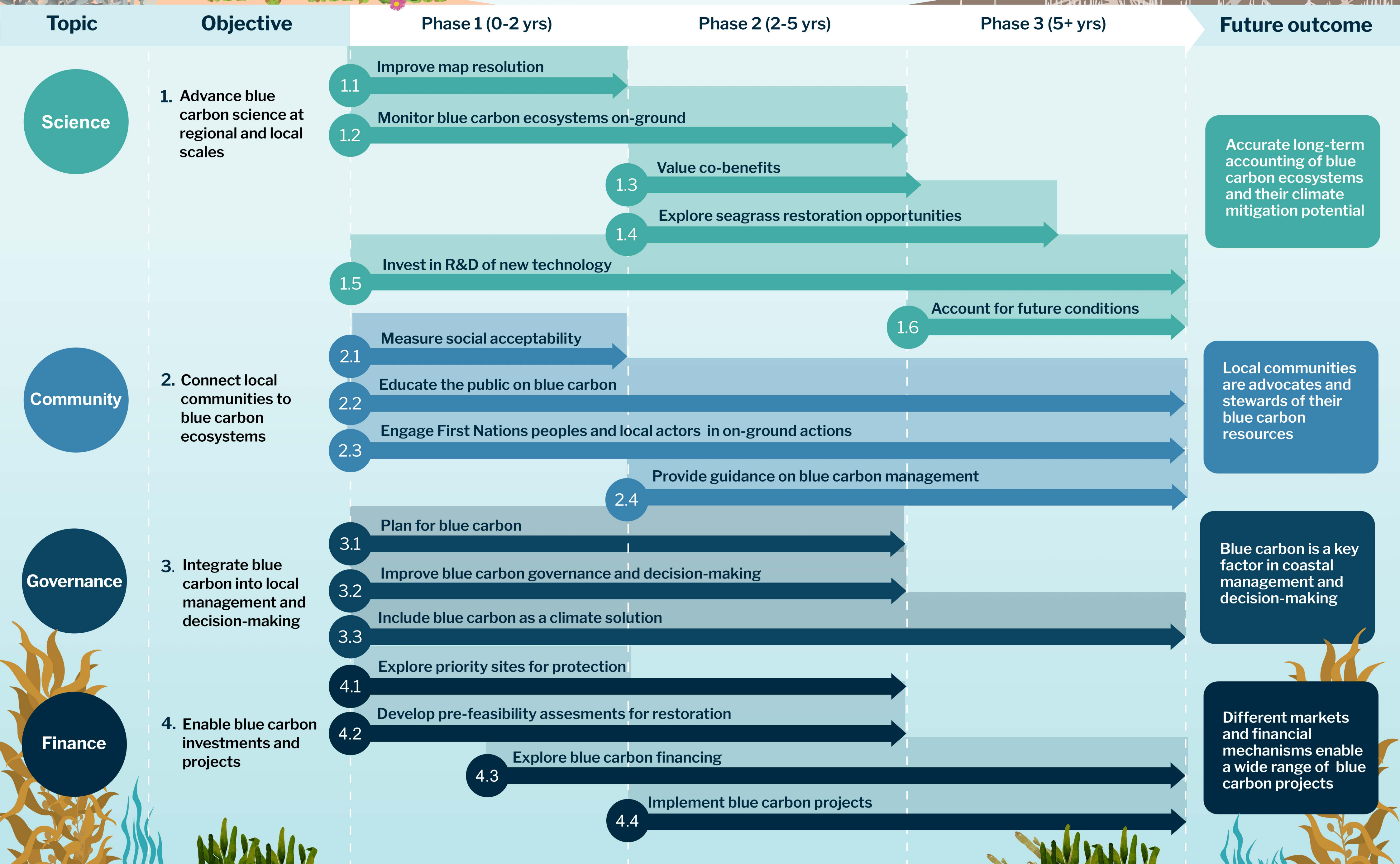
Blue Carbon Roadmap

Blue Carbon Roadmap



Costa MDP, Palacios MM, Macreadie PI, 2022. Blue carbon opportunities at a local scale within the Western Port Bay and eastern Port Phillip Bay. Deakin University, Australia. 121 pp.

Objective 1

Advance blue carbon research at regional and local scales

ACTION 1.1

Improve map resolution

ACTION 1.2

Monitor blue carbon ecosystems on-ground

ACTION 1.3

Value co-benefits

ACTION 1.4

Explore seagrass restoration opportunities

ACTION 1.5

Invest in R&D of new technology

ACTION 1.6

Account for future conditions

Objective 1

Advance blue carbon research at regional and local scales

Advancing research priorities across Western Port Bay and eastern Port Phillip Bay's blue carbon ecosystems will enable accurate accounting of local blue carbon assets and their climate mitigation potential. The availability of local datasets will also facilitate the development of future protection and restoration projects.

ACTION 1.1
Improve map resolution

Develop high-resolution distribution maps of blue carbon ecosystems

The best available coastal vegetation maps in Victoria were developed by Boon et al. (2011), which systematically mapped the distribution of mangroves and saltmarshes along Victoria's coastline. This dataset was based on a composite of different satellite imagery at different resolutions, and unfortunately, is now outdated. Overall, this can limit the analysis of the distribution of mangroves and saltmarshes at a local scale since the distribution of these ecosystems can substantially vary through space and time.

To fulfil these gaps, councils could invest in the development of high-resolution maps (i.e., using satellite imagery with resolution at 10-30 m from freely available collections such as Sentinel-2 or Landsat) that allow for the quantification and monitoring of blue carbon ecosystems through space and time.

With imagery available since 1972, the Landsat collection is particularly useful as it allows for exploring long-term changes in ecosystem distribution (Lymburner et al. 2020, Murray et al. 2022). However, when choosing the best resolution to map blue carbon ecosystems it is important to consider the mapping aims, the scale, and the available funds (Malerba et al. 2023).

Regular mapping of seagrass meadows (every 3-5 years) should be prioritised. Over the last 50 years there have been several seagrass mapping initiatives throughout Victoria, however, the dataset is not continuous with gaps as large as 20 years between mapping efforts. Further, most of these initiatives were limited by the mapping capabilities at the time of the study (e.g., Lynch 1966, Blake and Ball 2001), with remote sensing technologies and approaches advancing significantly in the past decade.

Given the technical difficulty of using satellite technology to characterise underwater plant communities, only recent mapping studies provide high-quality estimates of seagrass extent in Western Port (Dalby et al. 2022) and Port Phillip Heads Marine National Park (Carnell et al. 2021).

Past studies based on ground-truthing in combination with hand-drawing over aerial images (such as in Blake and Ball 2001) are time-consuming and difficult to reproduce. In contrast, new remote sensing technologies and approaches (see Roadmap Action 1.5). could be easily replicated and expanded throughout Western Port Bay and eastern Port Phillip Bay to identify potential areas for restoration.

Data and maps could be shared and made publicly available so they can be used by councils, scientists and managers to adjust coastal strategies (in support of Roadmap Actions 3.1 and 3.2), identify areas on decline in need of protection or restoration (as per Roadmap Actions 4.1 and 4.2), enable ecosystem accounting (in support of Roadmap Action 1.3), address knowledge gaps in Victoria's blue carbon ecosystems, and undertake a local coastal risk assessment and adaptation planning.

The wetland monitoring program developed to map Queensland's wetlands is a good example of a large-scale monitoring program that could be replicated at regional and local scales in Victoria. The baseline map was released in 2006, and since then, eight other versions have been released to update the distribution extent of wetlands in the state. The most recent map was released in 2021 and included in the online platform WetlandInfo.

ACTION 1.2

Monitor blue carbon ecosystems on-ground

Invest in the long-term monitoring of blue carbon ecosystems and the collection of on-ground carbon datasets (e.g., sequestration and fluxes) to detect the drivers of spatial and temporal changes over time.

Temporal monitoring of coastal wetlands is key to environmental accounting and understanding the carbon gains or losses of these ecosystems through time. Except for short-term site-specific projects, there is currently no long-term monitoring program of Victoria's coastal vegetated ecosystems that enables detecting changes in the ecosystem condition and carbon sequestration over time. To address this knowledge gap, it is important to expand the Victorian Coastal Monitoring Program (currently focused on geophysical datasets) to include long-term ground data collection on selected mangrove, saltmarsh, and seagrass sites. On selected sites, on-ground data on plant species richness, cover, distribution, and ecosystem condition could be regularly collected with the help of citizen scientists (aligned with Roadmap Actions 2.2 and 2.3) to create a long-term monitoring dataset.

In addition, it is recommended to collect on-ground measures of soil carbon sequestration rates and greenhouse gas fluxes across a wide range of ecosystem settings in the region to get accurate estimates of the local blue carbon budget and climate mitigation potential (net carbon sequestration after considering carbon capture and releases).

Although, several studies across Victoria have highlighted the blue carbon potential across the state (for example, Ewers Lewis et al. 2018, 2020), data on soil carbon sequestration rates and fluxes (e.g., methane and carbon dioxide) remains limited and sparse, with most estimates being produced from a handful of sites. Further, although there are important datasets on plant and soil carbon stocks across Western Port and Port Phillip Bays (e.g., Ewers Lewis et al. 2018, 2020, Serrano et al. 2019) more research needs to focus on understanding the drivers of spatial and temporal blue carbon variability.

Carbon stocks, sequestration rates and fluxes are known to significantly vary across locations depending on the specific biological, environmental, and physical conditions of the sites (i.e., plant species, sediment inputs, environmental conditions, tidal inundation; Serrano et al. 2019, Ewers Lewis et al. 2020, Costa et al. 2021, Young et al. 2021).

Carbon sampling could follow standard international protocols (e.g., blue carbon manual from Howard et al. 2014; mangrove sampling standards from Kauffman and Donato 2012), so values can be compared across time, space and studies. Soil cores collected for carbon stocks can be analysed in laboratories that hold an elemental C:N analyser (e.g., Deakin University), while samples collected for carbon sequestration rates require processing in a ^{210}Pb age-dating facility (e.g., CSIRO, Edith Cowan University). Institutions with greenhouse gas analysers (e.g., Deakin University, Monash University, University of Melbourne) would need to be contacted to undertake carbon dioxide, methane, or nitrous oxide measurements on coastal wetlands.

ACTION 1.3

Value co-benefits

Quantify and value ($) other ecosystem services using an environmental accounting framework.

Blue carbon ecosystems provide many ecosystem services important for both climate mitigation and adaptation. While the focus is on their carbon drawdown capacity for climate mitigation, a growing number of studies in Victoria highlight that blue carbon co-benefits (e.g., nitrogen fixation, coastal resilience, biodiversity enhancement) can provide as much - or even more - value and revenues (Carnell et al. 2019, 2022b, Huang et al. 2020, Jänes et al. 2020a, 2020b, Costa et al. 2022b). These studies provided a first-pass valuation of ecosystem services, but we still lack more mechanistic models to estimate these benefits.

Some of the blue carbon co-benefits that should be explored and valued include, but are not limited to:

- **Coastal protection**
- **Biodiversity and fisheries enhancement**
- **Nitrogen fixation**
- **Water purification**
- **Social and Cultural services**

As part of this report, we have prepared preliminary estimates of the blue carbon co-benefits in Western Port Bay and eastern Port Phillip Bay (see Results & Discussion section), however, detailed assessments to estimate their potential value using an environmental accounting approach, such as the UN's System for Environmental-Economic Accounting - Ecosystem Accounting (SEEA EA, UNCEEA 2021; further information available at https://seea.un.org/ecosystem-accounting), is still needed to understand the value of local coastal wetlands in the study region. A key co-benefit that remains largely understudied is the cultural and social value of Victorian coastal wetlands. In alignment with DEECA's Marine and Coastal Strategy (Action 1), First Nations peoples should be encouraged to assess bio-cultural values and undertake cultural mapping, while monitoring the impacts of land use and climate change across Sea Country.

Several international standard accounting frameworks can be used to value natural capital in the region. The SEEA EA is one of the frameworks increasingly being implemented to account for Australia's natural capital by measuring the ecosystem services, tracking changes in ecosystem assets, and linking this information to economic and other human activities.

There is a large knowledge gap in the potential areas available for seagrass restoration in Victoria. Research on the additionality opportunities combined with the most cost-effective methods for seagrass restoration can potentially lead to significant blue carbon opportunities for most councils.

ACTION 1.4

Explore seagrass restoration opportunities

Invest in research to understand the potential restoration opportunity for seagrasses and kelps

The large uncertainties related to the restoration of seagrass in Victoria (e.g., what are the main local drivers of degradation and how to effectively cease them, what are the most cost-effective methods for local restoration, how to improve seagrass survival rate), along with the lack of information on additionality opportunities, limit our current capacity to estimate the return on investment from management actions to restore this complex ecosystem.

In addition to addressing the current mapping deficiency of blue carbon ecosystems (as per Roadmap Action 1.1), it is important to undertake spatial research to understand the potential restoration opportunity for seagrass meadows and kelps across Western Port and Port Phillip Bays. This can be achieved by using remote sensing techniques or participatory resource mapping to extract local knowledge from seagrass experts and/or community groups to help mapping their restoration opportunity.

Developing high-resolution maps on the additionality opportunities for seagrasses and kelps will open the possibility of estimating the return on investment from additional management actions to restore these ecosystems within coastal councils. Councils with extended coastlines (e.g., Mornington Peninsula) or lack of mangrove or saltmarsh ecosystems (e.g., Kingston) could significantly benefit from exploring seagrass restoration opportunities.

ACTION 1.5

Invest in R&D of new technology

Invest in new techniques to improve restoration outcomes and technologies to facilitate the monitoring of blue carbon ecosystems (e.g., remote sensing, drones).

The restoration of blue carbon ecosystems can be challenging due to the natural complexity of the intertidal coastal environment, the presence of lingering degraded conditions (e.g., bare exposed soil), and the specific requirements that pioneering plant species need to establish and thrive. To improve the success of restoration outcomes in Western Port and Port Phillip Bays, it is recommended to invest in innovative approaches for active restoration that assist mangroves, saltmarshes and seagrasses to quickly reach 'establishment thresholds' and develop into thriving ecosystems. For example, teams from the Western Port Seagrass Partnership, the University of Melbourne and Deakin University have been trialling different structures (e.g., slotted PVC tubes, 3D-printed concrete planters, 3D potato-starch lattices) designed to dissipate wave energy, stabilise the soil, and facilitate the attachment of seedlings or seeds (see Box 3). These local research projects are producing important preliminary results, however, more research into assisted restoration interventions is required to actively speed up the revegetation of degraded coastal sites in the region and improve the environmental outcomes of restoration projects.

Additionally, R&D should focus on the development of advanced observation technology and analytical tools that facilitate tracking at a low cost any spatial and temporal changes of blue carbon ecosystems at local scales. For example, recent projects conducted in Western Port have used Motion and Multi-view stereo imagery from unmanned aerial vehicles (UAV; drones) to quantify mangrove plant carbon stocks (Navarro et al. 2020) and utilised remote sensing techniques to successfully map the distribution and land cover change of mangrove and saltmarsh ecosystems across a 10+ year period (Navarro et al. 2021). Expanding R&D in remote sensing techniques, LiDAR and radar sensors, and artificial intelligence tools could significantly reduce the time, labour and cost required to implement a blue carbon monitoring program across the Western Port and Port Phillip Bays (as per Roadmap Actions 1.1 and 1.2) and facilitate tracking the environmental outcomes from restoration and conservation projects (in support of Roadmap Action 4.4).

BOX 3.

Opportunities for active restoration

Active restoration involves accelerating the recovery of a degraded ecosystem by implementing a series of abiotic or biotic interventions (Atkinson and Bonser 2020). While abiotic interventions usually include the active remediation of substrate conditions, biotic interventions refer to the reintroduction of depleted species (e.g., revegetation) and the management of invasive pests.

Globally, most blue carbon restoration programs focus on ceasing the source of degradation at a local scale (e.g., improvement of water quality and sedimentation) and allowing the ecosystem to follow a natural trajectory of ecological succession (a.k.a. passive or natural restoration). Active restoration programs are labour-intense and costly so they tend to only be used in cases where passive approaches would almost certainly fail.

The Western Port Seagrass Partnership has trialled and refined several revegetation techniques for mangroves at three Western Port sites (Grantville, Lang Lang South and Lang Lang North; Parry 2019, Parry 2021). Some of the refined planting methods included planting seedlings or seeds within slotted PVC tubes (inserted either 10 cm or 2.5 cm into the sediment) or planting seeds attached to bamboo stakes (a.k.a staked seed method).

Results showed the slotted PVC approach did not necessarily favour mangrove survival, as the presence of the tube truncated the growth of lateral roots and most often led to mangrove death upon tube extraction (due to breakage of the tap root or sediment erosion). Interestingly, results from Grantville suggested that seeds planted with the staked seed method can have similar survival rates to planted seedlings (9 months old). Given the high cost of growing mangrove seedlings for restoration projects, optimising effective seed plantation techniques should be further explored to make large-scale restoration more feasible (Parry 2021).

More recently, a new initiative from Deakin University is trialling the use of biodegradable structures to support the establishment of mangrove, seagrass, and saltmarsh species in coastal areas where harsh conditions and historical degradation limit passive restoration success. The approach involves the deployment of 3D lattices made of compostable potato starch and wood fibres (produced by BESE-elements®) that promote seed, seedling, and root establishment. For example, the structure slows water movement, allowing for soil accumulation and seed capture. Roots of seedlings or co-transplanted plants are able to establish as the structures stabilise and allow oxygenation of the soil.

These structures have resulted in positive revegetation results for seagrass and saltmarsh ecosystems in Europe and North America, and are currently being deployed and trialled in several sites across Western Port and Port Phillip Bays (e.g., Corinella, Queensferry, Altona). If successful, this approach of assisted restoration could significantly improve the environmental outcomes of blue carbon projects in the region, allowing local councils to efficiently restore their coastal wetlands and the ecosystem services they provide (e.g., carbon sequestration, biodiversity, coastal protection).

More information on these biodegradable structures is available on the [#ReGenOurCoasts program website].

ACTION 1.6

Account for future conditions

Invest in research to understand the impacts of climate change on the distribution of blue carbon ecosystems and their carbon sequestration and storage potential

Climate change will significantly impact the distribution and carbon cycling dynamics of coastal ecosystems by altering current regimes of tidal inundation (i.e., sea-level rise), sea temperature, rainfall, and sediment dynamics across Australia's coastlines (Rogers et al. 2019, Saintilan et al. 2019, Young et al. 2021). To identify how these climatic and oceanographic changes will impact blue carbon assets in Western Port and Port Phillip Bays, it is useful to undertake spatial modelling research that informs councils how local blue carbon ecosystems will respond under future conditions (e.g., predicted inundated extent from sea level rise plus storm surge in 2040 (20 cm), 2070 (47 cm) and 2100 (82 cm); Department of Environment Land Water and Planning 2018c).

Although this research will only be possible with the development of high-quality distribution maps of blue carbon ecosystems and their stocks, along with spatially explicit data on the main drivers (e.g., elevation, slope, land use, sediment), it will become more necessary over the next 5+ years with the exacerbation of climate change. Accounting for future conditions will enable councils and project developers to better predict the environmental and economic outcomes of blue carbon projects (as per Roadmap Actions 4.2 and 4.4), while improving local capacity to plan and manage these carbon assets.

Objective 2

Connect local communities to blue carbon ecosystems

ACTION 2.1

Measure social acceptability

ACTION 2.2

Educate the public on blue carbon

ACTION 2.3

Engage First Nations People and local actors in on-ground actions

ACTION 2.4

Provide guidance on blue carbon management

Objective 2

Connect local communities to blue carbon ecosystems

First Nations Peoples, local communities, and relevant stakeholders should be educated about Blue Carbon and engaged in all the planning and decision-making concerning local coastal ecosystems. Their support and commitment are indispensable for the success of blue carbon projects.

ACTION 2.1

Measure social acceptability

Investigate community acceptability towards blue carbon ecosystems and project development.

Local stakeholders can be enablers or constraints of blue carbon projects. Hence, it is important to explore what are the local perceptions, social values, and concerns towards (a) blue carbon ecosystems and the (b) implementation of projects to restore or protect them. Evidence from other parts of Australia shows that even if landholders have positive attitudes towards mangrove or saltmarsh ecosystems, they might not necessarily be keen to restore them on their properties.

This assessment of social and cultural acceptability can be achieved via public consultations, online questionnaires, or targeted stakeholder workshops (e.g., First Nations peoples, farmers). This information is critical to address any misconceptions about blue carbon ecosystems, tailor effective education and engagement programs, and guarantee that on-ground projects are designed to meet highly valued community needs.

ACTION 2.2

Educate the public on blue carbon

Promote blue carbon education and awareness and address any potential landholder hesitancy to projects.

One of the underlying causes of blue carbon ecosystem degradation is the lack of awareness of their importance. With support from First Nations peoples, tailored training and capacity-building programs should be developed to raise awareness of the multitude of ecosystem services coastal wetlands provide (e.g., carbon sequestration, biodiversity enhancement, coastal protection, cultural value) and their critical role for climate mitigation and adaptation.

Additional to increasing knowledge, education should focus on connecting the public to these ecosystems (e.g., via immersive citizen science programs or hands-on restoration actions) and encouraging stewardship that leads to positive behavioural changes towards them.

Educational programs should be directed to key audiences (e.g., landholders, managers, First Nations Peoples, youth) and supported by tailored outreach campaigns with scientific information and relevant calls to action.

An educated community that understands blue carbon ecosystems will be more likely to support projects to protect or restore them.

ACTION 2.3

Engage First Nations People and local actors in on-ground actions

Enable community and First Nations Peoples' participation in blue carbon citizen science projects, as well as local conservation and restoration actions

Community engagement programs around blue carbon ecosystems are critical to delivering Victoria's Marine and Coastal Strategy. Additional to directly contributing to coastal actions and science, they are an effective way of raising public awareness, connecting the public to local coastal ecosystems, and creating social cohesion.

First Nations Peoples and local communities across Western Port Bay and eastern Port Phillip Bay should be encouraged to be stewards of their blue carbon resources and be empowered to take direct on-ground actions to monitor them, protect them, enhance them, or restore them.

Community-led actions on blue carbon ecosystem help deliver environmental outcomes, while increasing public awareness and connection to coastal habitats.

Local councils should champion and increase support to community groups actively working in coastal wetlands (e.g., Western Port Seagrass Partnership, Landcare & Coastcare groups such as OZFish Unlimited), as well as encourage the creation of more citizen science programs or coastal initiatives (restoration or protection) directed towards blue carbon ecosystems.

Funding from Coastcare Victoria Community Grants or Victoria's Community Climate Change Adaptation (3CA) Program can provide initial resources for local community groups to deliver on-ground coastal actions and scientific research. However, more funding at a regional and local-scale is required to have a meaningful long-term impact on the target communities and ecosystems. Tailored blue carbon citizen science programs are often delivered by Deakin's Blue Carbon Lab (#BlueCarbonArmy) or Earthwatch's MangroveWatch, but there are currently no long-term state-wide or local initiatives.

When engaging local actors, First Nations Peoples should be actively engaged and empowered to care for, protect and improve their coastal environment, including blue carbon ecosystems (as per the Victorian Marine and Coastal Strategy: Action 1). This can be achieved by developing or expanding Sea Country ranger programs and supporting First Nations Peoples to undertake coastal research (asses cultural value, undertake cultural mapping) or on-ground management actions.

ACTION 2.4

Provide guidance on blue carbon management

Support and incentivise landholders and First Nations Peoples interested in protecting or restoring blue carbon ecosystems within their lands.

The management and enhancement of blue carbon ecosystems for climate change mitigation and adaptation is still rather new knowledge for many communities. Hence, it is important for councils to provide advice and support to local community members interested in managing coastal habitats within their properties for climate mitigation, coastal resilience, or biodiversity enhancement. Information and support could be offered through information sessions, a communications package, a dedicated webpage, and practice notes. Relevant information includes evidence-based facts on the carbon sequestration capacity of coastal wetlands and their ecosystem co-benefits, the best practices for managing these ecosystems, and an overview of financial opportunities from their protection or restoration.

As per Victoria's Marine and Coastal strategy (Activities 2.3, 2.4), it is important for local councils to seek fair and equitable economic incentives for the restoration and conservation of blue carbon ecosystems. In this regard, the Australian Emissions Reduction Fund (ERF) can offer economic incentives (in the form of carbon credits) to landholders that remove bund walls and restore tidal inundation on their properties (see Box 5). However, local councils should seek additional funds to help finance the implementation of other restoration strategies on private land (see Roadmap Action 4.3). Although, the Victorian Government has been supporting the private restoration of coastal wetlands through several initiatives (e.g., Landcare grants, the Port Phillip Bay Fund, Wetland Tender), the funding has been ad-hoc and the projects are only at small-scale. In the future, DEECA is expected to develop a state-level framework for optimising future investment in blue carbon ecosystems.

Objective 3

Integrate blue carbon into regional and local legislation and policy

ACTION 3.1

Plan for blue carbon

ACTION 3.2

Improve blue carbon governance and decision-making

ACTION 3.3

Include blue carbon as a climate solution

Objective 3

Integrate blue carbon into local management and decision-making

Blue carbon should become a key factor in coastal decision-making and local climate mitigation efforts. To achieve this, local authorities must facilitate the establishment and governance of public, private and First Nations projects aiming to protect and restore coastal blue carbon habitats.

ACTION 3.1

Plan for blue carbon

Embed blue carbon in local coastal planning, management, and decision-making.

At a national and state level, many policies, strategies, and plans (e.g., Victoria's Marine and Coastal strategy, Victoria's Climate Change Strategy 2021) have increasingly recognised the need of protecting and enhancing blue carbon ecosystems for climate change mitigation and adaptation. Local councils should update local planning and management documents to include the best available blue carbon science and align with national and state policies and strategies surrounding the protection and restoration of blue carbon ecosystems, now and into the future.

To facilitate embedding blue carbon into local documents, local managers and decision-makers should receive training and capacity building (as per Roadmap Action 2.2) to ensure they have the knowledge, skills, and capacity to make informed evidenced-based planning and management decisions around blue carbon assets.

As part of this process, each council should work with relevant First Nations Peoples, community members and local actors to guarantee a coordinated and publicly accepted approach to coastal planning, management, and decision-making. Within the new Marine and Coastal Act (2018) there is a provision for Regional and Strategic Partnerships (RASP) where there are regional-scale issues that require cross-institution and stakeholder cooperation to address. While implementing a RASP is still being trialled in some pilot projects, we recommend developing a RASP across Western Port Bay and eastern Port Phillip Bay to focus on blue carbon ecosystem restoration and protection actions. Such a RASP would involve government (e.g., councils), institutions (e.g., Melbourne Water, Parks Victoria), First Nations Peoples (Bunurong Land Council Aboriginal Corporation), and research institutions (e.g., Deakin University, Monash University, University of Melbourne). The focus of the RASP would utilise this Roadmap to accelerate project development and capital investments in blue carbon ecosystems in the region.

ACTION 3.2

Improve blue carbon governance and decision-making

Work alongside state government to define targets for blue carbon projects and clarify land tenure under future sea level rise.

Blue carbon ecosystems and their climate mitigation potential are increasingly recognised within different levels of policy and legislation instruments within Australia, however, we still face some uncertainties in governance regarding the development and implementation of blue carbon projects. A new review of legal frameworks and strategies supporting coastal wetland restoration in Victoria and Australia (Wartman et al. 2022) highlights that while blue carbon ecosystems have been widely recognised in new and updated state-level documents (e.g., Victoria's new Marine and Coastal Strategy via Action 2.4), there is a lack of specific restoration targets for on-ground projects or details on how to fund coastal actions (Wartman et al. 2022).

Similar to climate change or biodiversity targets, state and local governments should prioritise developing specific restoration and conservation targets for coastal wetlands that facilitate measuring and reporting time-bound progress. Equally important, it is recommended that governments identify and commit specific funds to achieve these blue carbon restoration targets (see Roadmap Action 4.3).

Sea level rise will significantly change the distribution, carbon storage capacity and restoration opportunities of blue carbon ecosystem across the region (e.g., Young et al. 2021, Moritsch et al 2021, Costa et al. 2022b). Hence, it is important for governments to plan and account for future conditions under sea level rise to help coastal communities to adapt and mitigate potential risks from coastal hazards. The role that coastal wetlands play as nature-based solutions has been recognised in the Victoria's Resilient Coast: Adapting to 2100+; which aims to guide land managers willing to consider restoring coastal wetlands to adapt to future conditions. Therefore, coastal councils could facilitate the planning for managed retreat (Figure 2) for coastal wetlands, so these ecosystems have enough accommodation space to migrate with the gradual inundation of sea level rise.

Enabling governance of blue carbon projects at regional and local scales can be facilitated in several ways. In Crown land, this may involve clarifying legislation around land tenure under sea level rise where blue carbon projects could produce Australian Carbon Credit Units (ACCUs). In private land, there could be a focus on providing relevant guidance on project development, access to economic benefits and supporting permanent protection agreements (as per Roadmap Action 2.4). For example, it is recommended to develop a 'blue carbon project decision tree framework' that summarises all the relevant blue carbon regulations and clarifies all the specific planning, permits, and approvals required to implement coastal wetland restoration projects in the region. We expect this document will be a key resource for landholders and First Nations Peoples (in support of Roadmap Action 2.4) that will facilitate project implementation (Roadmap Action 4.4).

ACTION 3.3

Include blue carbon as a climate solution

Incorporate blue carbon sinks in the achievement of local climate mitigation targets

Victoria has committed to reaching Net Zero emissions by 2050 (Victoria Climate Change Act 2017). To achieve this, local governments must play a critical role in reducing carbon emissions and implementing natural climate solutions to offset their remaining carbon footprint.

The protection and enhancement of local blue carbon ecosystems can help many councils reduce their carbon footprint and get closer to Net Zero emissions. By incorporating the conservation and enhancement of blue carbon assets within local strategies, many local councils can highlight their commitment to adapting and mitigating climate change, as well as account and report on their blue carbon potential.

Objective 4

Enable blue carbon investment: feasibility of developing a blue carbon restoration project

ACTION 4.1

Explore priority sites for protection

ACTION 4.2

Develop pre-feasibility assessments for restoration

ACTION 4.3

Explore blue carbon financing

ACTION 4.4

Implement blue carbon projects

Objective 4:

Enable blue carbon investment and project development

Exploring and promoting pathways for blue carbon investment will facilitate the uptake and implementation of projects aiming to protect or restore regional blue carbon hotspots. Market and non-market mechanisms should be considered to cover the costs of undertaking management actions that improve carbon sequestration, enhance biodiversity, and boost the ecosystem services of local coastal wetlands.

ACTION 4.1

Explore priority sites for conservation

Investigate priority sites for the conservation of blue carbon ecosystems to guide investments and conservation policy

Local sites for blue carbon conservation should be identified through the development of modelled heatmaps of blue carbon ecosystems and soil carbon stocks. Although several state-wide assessments have been prepared in the past (Ewers Lewis et al. 2020, Moritsch et al. 2021, Young et al. 2021), their coarse resolution limits their full applicability at local scales. Councils interested in identifying and protecting local areas with the highest blue carbon assets should combine on-ground local blue carbon data points (outputs from Roadmap Actions 1.1 and 1.2), with local spatial data on the main ecological, geomorphological, and anthropogenic drivers of blue carbon (e.g., temperature, soil type, population). Additional data (e.g., land tenure, community support) can help identify sites where protection is most needed, cost-effective, and where the likelihood of success is high.

ACTION 4.2

Develop pre-feasibility assessments for restoration sites

Develop pre-feasibility assessments and cost-benefit analyses for the implementation of restoration projects

A major challenge to implementing blue carbon restoration projects is knowing where to start. To tackle this, it is highly recommended to establish an inventory of potential sites for on-ground restoration that can be easily used by investors (e.g., local councils or donors) to compare restoration projects and identify the one that best suits the outcomes (environmental or social), costs, or risks they are willing to take. The restoration areas identified through this project are an obvious starting point but could be added to sites suggested by local stakeholders where restoration actions aside from fencing and tidal reinstatement would be required. Regarding tidal reinstatement, there is also the potential to investigate the blue carbon opportunities for non-mapped levees, which were not included in this study.

During the development of the portfolio, it is important to examine a wide range of blue carbon projects that vary in scale, narrative, and management intervention.

For example, we only explored blue carbon opportunities from three management actions [(1) tidal reinstatement, (2) fencing, and (3) managed sea-level retreat (Table 2, Figure 2)]. Alternative actions for blue carbon ecosystems such as enhancing sediment supply, avoided soil disturbance, active restoration using biodegradable structures or hybrid green-grey restoration, or revegetation of seagrasses (Kelleway et al. 2020) could also provide restoration opportunities in the region. As detailed in Box 2, councils could potentially also explore opportunities from the improved management of freshwater wetlands.

The portfolio should include a pre-feasibility assessment for each potential restoration site, with information on:

Scale of blue carbon opportunity

Potential co-benefits

Restoration methods

Land tenure and carbon ownership

Stakeholder amenability

Cultural overlays

Cost-benefit analysis

As suggested in the 2022 Victoria's Resilient Coast Plan, these types of assessments can be conducted at three different scales (large-, regional- and small-scale) depending on the stage of project development. While the table below (Table 4) focuses on blue carbon, these assessments can also include estimates of the co-benefit coastal wetlands provide.

Table 4. Description of the three management scenarios considered in this study, including rationale, methods, and assumptions. Adapted from Victoria's Resilient Coast: Adapting for 2100+ (2022).

Step	Scale	Description	Case study
1	Large scale	Review blue carbon data available at national/state level to identify known restoration opportunities	State-level assessment: Mapping the benefits and costs of management actions for coastal wetlands in Victoria (Box 4)
2	Regional scale	Undertake a tailored spatial assessment according to the desired spatial scale to identify specific opportunities and priority actions	This study.
3	Small scale	Undertake detailed investigation and modelling to inform on-ground works for blue carbon protection / restoration. and the development of feasiblity assessments This includes on-ground data collection at target sites. This is particularly important at sites where restoration actions may be complex, such as hydrological restoration/bund wall removal where a local scale hydrological model needs to be developed. In addition, local soil carbon data can also be collected to provide accurate predictions of blue carbon gains with restoration.	Site-level assessment: Hydrological modelling from levee removal in the Avalon Coastal Reserve (Box 6)

BOX 4.

State-level assessment: Mapping the benefits and costs of management actions for coastal wetlands in Victoria

A new state-wide assessment provides spatial information on current and potential future blue carbon ecosystems along Victoria's coast (including feasible areas for the restoration or expansion of blue carbon ecosystems through different management options), and the areas that provide a higher return in investment based on environmental-economic analyses.

The following management actions are being considered in different scenario combinations:

- Fencing
- Tidal reinstatement
- Managed sea- level retreat
- No management action (where current blue carbon ecosystems are lost due to erosion)

For each scenario, in addition to estimating the carbon sequestration opportunities (i.e., soil carbon sequestration), other ecosystem services were also estimated, such as fisheries (commercial and recreational), nitrogen sequestration, and coastal hazard mitigation.

Overall, the project developed spatial information on costs and benefits for multiple management actions to restore coastal wetlands, and their corresponding net benefits, which could then be used for land managers to identify potential blue carbon opportunities on their land. By restoring and/or conserving blue carbon ecosystems within their lands, coastal managers are contributing to mitigate the inundation, erosion, and damages from extreme weather events.

The combined benefit (i.e., nitrogen and carbon sequestration, fisheries, and coastal protection) provided by existing mangroves, saltmarshes, and seagrasses in Victoria is approximately AUD120.9 billion per year. If these ecosystems are restored at a large scale, Itidal reinstatement plus managed retreat had the highest cost at AUD7.6 billion while also having the highest net benefit of AUD134.8 trillion after 50 years, and with a 5% discount rate. In contrast, fencing is the cheapest management action to restore mangroves and saltmarshes, delivering more than AUD140 billion after 50 years. The final report and outputs will be available through DEECA's CoastKit portal.

Graphical abstract detailing each step used in the environmental economic accounting used in this state-wide project (Costa et al. 2022b).

ACTION 4.3

Explore blue carbon financing

Explore different financial mechanisms to fund blue carbon projects (e.g., climate or biodiversity credits) and reduce financial barriers.

All the actions proposed on this Roadmap require long-term funding and resourcing. Hence, it is important to explore a wide range of finance mechanisms that together enable a strategic long-term investment program into blue carbon research, community engagement and project development.

Financing for blue carbon on-ground restoration projects is possible through climate - or biodiversity-related schemes such as market mechanisms (e.g., Voluntary Carbon Market, Australia's Emission Reduction Fund), government funds (e.g., federal, state) or other non-market mechanisms (e.g., philanthropy, private investment). The Federal Government has recently announced it plans to pursue developing a biodiversity crediting market in Australia, which if established could help fund restoration projects with proven biodiversity benefits.

Projects aiming to restore blue carbon ecosystems through the removal of tidal barriers are currently eligible to earn Australian Carbon Credit Units (ACCUs; Box 5), improving the financial return on the project investment. However, considering the high costs associated with the current blue carbon method, the return on investment based solely on the carbon market might not be feasible for most of the projects. In the near future, it might be possible to stack different types of credits (e.g., carbon + biodiversity + social credits) to further increase project returns and therefore, their feasibility.

Private investors and philanthropy can be effective alternatives to fund small-scale projects. Understanding the motivations and expectations of potential investors is critical to help them identify suitable projects from a portfolio of conservation or restoration sites (aligned with Roadmap Actions 4.1 and 4.2).

While some investors may not be interested in carbon capture, they may have other reasons to fund the restoration or protection of a blue carbon site (e.g., a special connection to the site or interest in enhancing the coastal habitat of an endangered species). In the near future, DEECA is expected to develop a state-level framework for optimising future investment in the protection and restoration of blue carbon ecosystems.

There are three other markets, that could be further developed to drive further investment into blue carbon ecosystem restoration.

Insurance Market

Companies are investigating the potential to capitalise on the coastal erosion and storm protection values of coastal ecosystems. By demonstrating that coastal wetlands significantly improve the resilience of coastal infrastructure impacted by storms, flooding, erosion and sea level rise, there is scope to provide a financial incentive for the restoration of these ecosysefs.

Nitrogen Market

Currently, Melbourne Water has a price on Nitrogen in the Port Phillip Bay catchment, for urban wetlands that reduce the nitrogen loads entering the bay and improve the water quality and ecosystem health. A similar program could be investigated for coastal wetlands, given their ability to store and cycle nitrogen.

Fisheries

In New South Wales, some commercial fisheries provide funding for protection and restoration actions of saltmarshes and mangroves given the dependence of their target fish species on these ecosystems. In Victoria, where recreational fisheries are quite important (particularly in Port Phillip and Western Port), the Victorian Fisheries Authority (VFA) provides funding to create artificial reefs and restore oyster reefs. Therefore, in Western Port Bay and eastern Port Phillip Bay a partnership with VFA could be sought to develop blue carbon restoration programs that enhance fisheries stocks.

BOX 5.
Australian 'blue' carbon credits

What is the Emission Reduction Fund?

The Emissions Reduction Fund (ERF) is a carbon scheme from the Australian Government that provides incentives for a range of organisations and individuals to adopt new practices and technologies to reduce their emissions.

A number of activities are eligible under the scheme and participants can earn Australian Carbon Credit Units (ACCUs) for emission reductions. Each ACCU represents one tonne of carbon dioxide equivalent net abatement (through either emissions reductions or carbon sequestration) achieved by eligible activities, such as the tidal restoration of blue carbon ecosystems. ACCUs are issued by the Clean Energy Regulator (CER) and can be sold to the government through carbon abatement contracts or in the secondary market.

Australia's first blue carbon method: tidal reinstatement

The blue carbon method enables ACCUs to be earned by projects that remove or modify tidal restriction mechanisms and allow natural tidal flow to be restored. This results in the rewetting of completely or partially drained coastal wetland ecosystems and the conversion of freshwater wetlands to brackish or saline wetlands.

The method enables ACCUs to be earned for the establishment of coastal wetland ecosystems that occurs passively as a result of the project activities. There are three components within coastal wetland ecosystems that contribute to carbon abatement for a blue carbon project:

- Soil carbon sequestration (through vertical accretion).
- Carbon sequestered in above- and below-ground vegetation biomass.
- Emissions avoided from introducing tidal flow.

Other blue carbon restoration activities (e.g., livestock exclusion through fencing, managed sea-level retreat) have been proposed to be included in Australia’s ERF.

ACTION 4.4

Implement blue carbon projects

Implement blue carbon projects and develop a network of demonstration sites.

Restoring and conserving blue carbon ecosystems at small and large scales can help Western Port and Port Phillip Bays achieve their Net Zero emission targets (via carbon sequestration), while enhancing the local resilience to climate change (via coastal protection, biodiversity enhancement, water purification). While small-scale projects are possible on most local councils, large-scale blue carbon opportunities would mainly be located in the councils of Casey, Cardinia and Bass Coast where there are larger areas of mangroves and saltmarshes that have been lost since European settlement.

All projects aiming to restore or protect blue carbon ecosystems should first undergo a robust planning stage (e.g., preparing feasibility and hydrological assessments, obtaining permits and consent, developing management and action plans) to maximise the chances of success and mitigate any potential risks. Once funding has been secured (as per Roadmap Action 4.3), the project delivery stage involves implementing the Restoration or Conservation Action Plan, by undertaking all the on-ground operations, management actions and monitoring activities.

Restoration projects eligible to earn ACCUs under Australia's Emission Reduction Fund (those involving removal of tidal barriers; see Box 5) must be registered to the Clean Energy Regulator before commencement and meet strict obligations on project permanence, reporting, and auditing during the life of the project. More information on implementing blue carbon projects under the ERF is available on the CER website.

Blue Carbon projects implemented in the region can be used as demonstration sites to illustrate the business case for investment, while testing governance frameworks (aligned with Roadmap Action 3.2), engaging local communities (in support of Roadmap Action 2.3), and putting science into on-ground action (aligned with Roadmap Action 1.5). The information and knowledge gained through demonstration projects will help de-risk, improve, and drive future investment into blue carbon projects in the region.

It is good practice to monitor all blue carbon projects in the region and actively share outcomes, data and learnings with scientists, the government, and the public. Knowledge exchange and data sharing will help increase the success of future restoration projects and improve restoration science by increasing the predictive capacity of restoration actions.

BOX 6.

Site-level assessment: Hydrological modelling from levee removal in the Avalon Coastal Reserve

The Avalon Coastal Reserve holds a series of decommissioned salt ponds, that could be restored back to saltmarsh ecosystems through the removal of levees and the reinstatement of natural tides. However, before any management action can be implemented on-ground hydrological and environmental assessments are required at this site.

Avalon Coastal Reserve is located south of the Avalon Airport in Victoria, near Geelong. It was originally a low-lying coastal wetland; however, the land has been purchased and leased by Cheetham Saltworks for the construction of a salt field. Operations in the salt field lasted until 2002, with only limited operations maintained until 2017 when Parks Victoria assumed responsibility for the management of the site.

As part of the Victorian Coastal Wetland Restoration Program, a carbon and hydrological assessment was undertaken at Avalon Coastal Reserve ((Gulliver et al. 2020, Heimhuber et al. 2021). Carbon cores were collected across several salt ponds and saltmarsh habitats for carbon stock analysis and age-dating (^{210}Pb). Given the complexity of the site and its location in an oceanic embayment, a detailed hydrodynamic model was also conducted to accurately predict the vegetation and inundation outcomes of different restoration options.

This project specifically aimed to optimise the restoration of the site for both shorebird habitat and blue carbon sequestration, while avoiding any conflicts with the cultural heritage and private properties. To find an optimal balance, the research team developed and tested a range of different restoration scenarios (i.e., no intervention, minimal modifications, substantial modifications, and fully engineered), which included the following steps:

1. Development of a detailed and well-calibrated hydrodynamic model to simulate the inundation regime of each of these scenarios.
2. Detailed RTK-GPS survey of relevant vegetation communities around the site to establish their elevation preferences.
3. Tidewater levels survey to establish the corresponding hydroperiods and inundation regime.

Then, all these data were combined and the linkages between hydroperiod and vegetation were then used to infer the vegetation outcomes of each restoration option from the hydrodynamic model results. Overall, this local information could also be used to estimate potential carbon abatement and co-benefits provided by the restoration project. Further information is available on the Program website or an interactive StoryMap.

Sediment cores collected during the carbon assessment (A-G). Dashed white line is horizon between an upper organic layer and the deeper levels of shell and gravel. (H) Hydrological survey.

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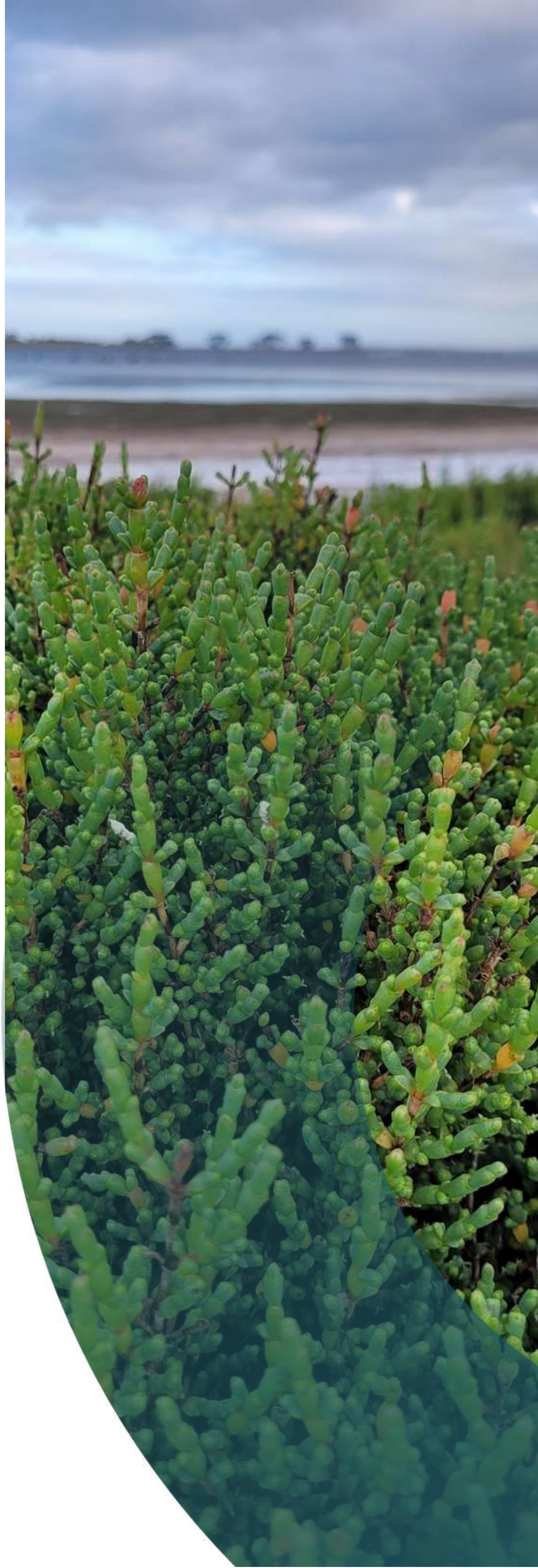

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