Opportunities for saltmarsh restoration & migration with sea level rise in Swan Bay, Victoria

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Executive Summary

Saltmarsh ecosystems are critically important to both biodiversity and lives and livelihoods along the Victorian coastline. However, roughly 50% of the saltmarshes in Port Phillip Bay have been degraded or converted to other land uses since European colonisation. This has had large impacts on a range of species, including the now critically endangered orange-bellied parrot (N*eophema chrysogaster*). The saltmarshes of Swan Bay represent a key pocket of intact coastal saltmarsh, but in many areas are threatened by current land use and by the slowly but surely advancing threat of sea level rise. Thus there is a need to understand options for saltmarsh rehabilitation and restoration opportunities that also consider options for saltmarsh migration with sea level rise.

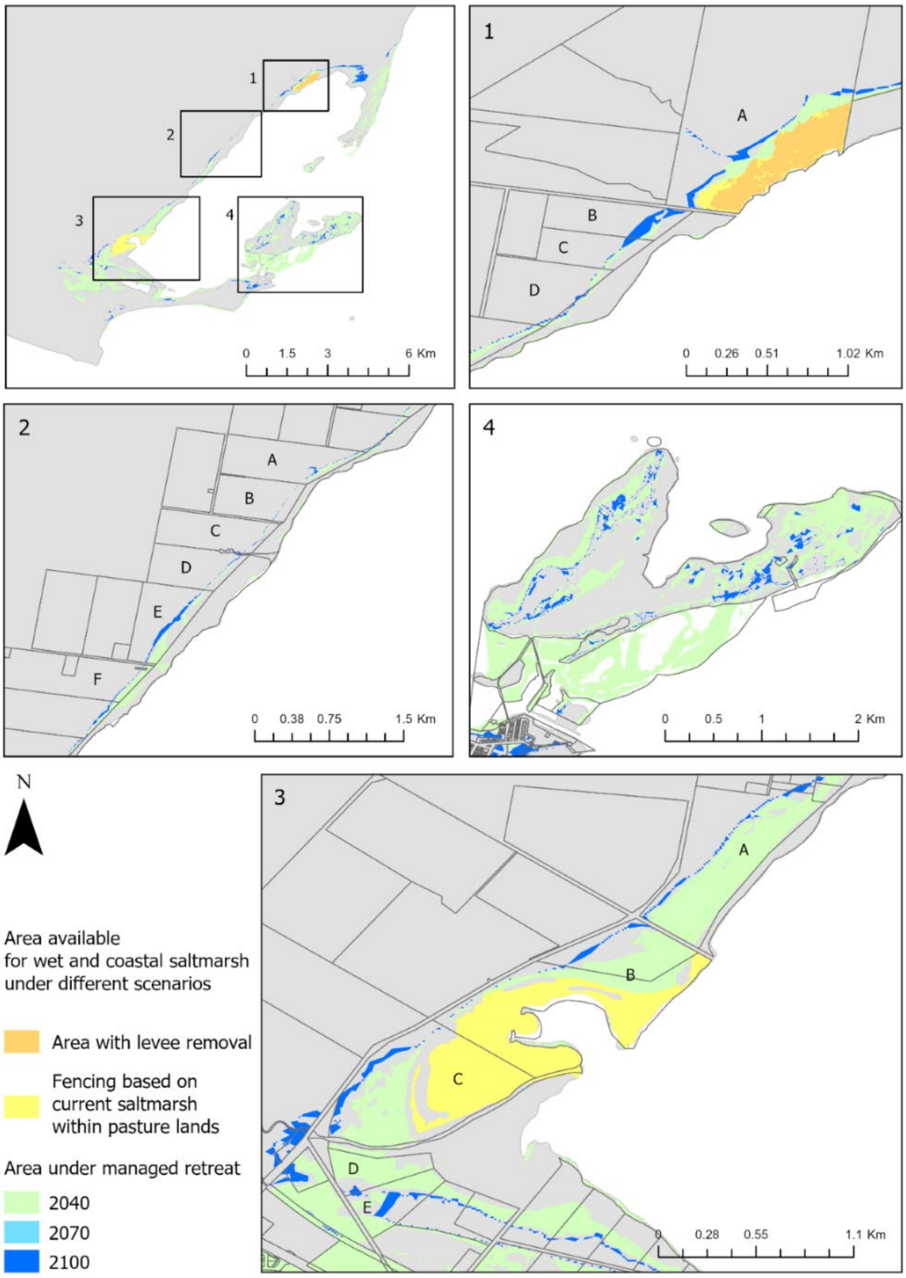
This first-pass wetland restoration assessment included a literature and policy review to understand key gaps in our knowledge, and the state of legislation and policy protecting saltmarshes and enabling active restoration actions. Once this was completed, we undertook a spatial assessment of restoration options by considering key management activities of reducing access by livestock (i.e. fencing) and by reinstating tidal flow (i.e. bund wall removal). We also utilised existing modelling of sea level rise projections by 2040, 2070 and 2100, to understand what areas would need to be considered to allow for saltmarsh migration in these timeframes. This was backed up by on-ground site condition assessments to ensure recommended actions were feasible, and matched with the available data used in the spatial assessment.

The spatial assessment indicated there are areas of saltmarsh which could be restored now through fencing (63 ha) and bund wall removal (21 ha). In addition, sea level rise and changing land use could see an additional 480 ha become saltmarsh by 2040, then another 84 ha by 2070 and 63 ha by 2100 (Summary Figure 2). Site assessments were conducted at key sites around Swan Bay, which included determining the current condition of the wetlands and existing saltmarsh, identification of key threats, collection of elevation data, as well as anecdotal knowledge from landholders. From here, we identified 15 properties where actions such as fencing (57 ha) and bund wall removal (15 ha) could see restoration of wet saltmarsh, which is prime habitat for the orange-bellied parrot (Summary Figure 1). In addition, there is over 60 ha of area which, through discussions with landowners, could become wet saltmarsh by 2040, and then another 10 ha by 2100.

Summary Figure 1. Site 3A in the south-west of Swan Bay represents an ideal site for restoration actions that can benefit saltmarsh now and into the future.

The results of this assessment highlight three broad actions that can be undertaken to protect and restore 143 ha of wet saltmarsh in Swan Bay; prime Orange-bellied Parrot habitat:

1. **Fencing of healthy & degraded saltmarsh areas. (57 ha)**
2. **Removal of bund walls and infilling of drains (15 ha)**
3. **Managed retreat to enable wet saltmarsh migration by 2040 -2100 (71 ha)**



Summary Figure 2. Wet saltmarsh restoration sites identified through spatial assessment of the various management options now (levee removal and fencing) and into the future through managed retreat. The property boundaries are shown to help identify landowners and labelled according to a unique numbering system and detailed in the report.

Introduction

Coastal wetlands such as saltmarshes provide a range of ecosystem services to coastal communities (Adams et al. 2021), and are some of the most productive and biodiverse ecosystem on the planet. Saltmarshes provide food and habitat to a range of species including crabs, fish and birds (Feagin et al 2010, Kelleway et al. 2017, Jänes et al. 2020), which in turn drives fisheries and recreational activities (Carnell et al. 2019). In southern Australia, coastal saltmarshes provide critical habitat for listed threatened species, such as the green and golden bell frog (*Litoria aurea*) and the orange-bellied parrot (N*eophema chrysogaster*), and migratory species such as the eastern curlew (*Numenius madagascariensis*), the Pacific golden plover (*Pluvialis fulva*), the sharp-tailed sandpiper (*Calidris acuminata*), and the red-necked stint (*Calidris ruficollis*). These and other bird species are valued by birdwatchers and local landowners alike (Weston *et al.* 2012, Carnell *et al.* 2019).

Unfortunately, despite these values, saltmarshes have been degraded and converted to other land uses both globally (Murray *et al.* 2022), and across the state of Victoria, Australia. Here, 34% of saltmarshes have been converted to other land uses such as salt production (eg. Avalon & Moolap), sewage treatment ponds (i.e. Werribee) and agriculture (eg. Swan Bay) since European colonisation (Sinclair and Boon 2012) in Port Phillip Bay. The saltmarshes in this region are particularly important habitat for the critically endangered Orange -bellied Parrot (N*eophema chrysogaster*), which feeds on and roosts in various saltmarsh plants including the beaded glasswort (*Sarcocornia quinqueflora)* and the shrubby glasswort (*Tectocornia arbuscula* (Loyn *et al.* 1986; Mondon *et al.* 2009). There are only an estimated 50 individual Orange-Bellied Parrots left in the wild, with the decline of this species been linked to loss of saltmarsh in this region (Menkhorst *et al.* 1990, Dreschler *et al.* 1998).

Given this dependence on saltmarsh for their survival, there has been a focus by management agencies on the restoration of saltmarsh ecosystems in the region, going hand-in-hand with captive-breeding and other management actions (Menkhorst et al. 1990, Stojanovic et al 2020). Here, the region of Swan Bay has been highlighted as both a critical area for Orange-Bellied Parrots currently, but with 15% loss of saltmarsh since European colonisation, potential to expand their current habitat. However, while there are maps of the pre-European distribution of saltmarsh across the region which can be used to guide areas for restoration, sea level-rise presents a challenge in both the short and long-term for saltmarsh restoration and management (Leo et al 2019, Raw et al. 2021. Indeed, with sea levels having already risen this has driven changes in the distribution of saltmarshes in the region already (Rogers et al. 2005, Whitt *et al.* 2020). But importantly, when planning restoration of new saltmarsh sites, it is important to consider if there is room for saltmarshes to expand into as sea levels continue to rise (Leo et al. 2019), and how we can best facilitate their migration. However, if we are able to maintain or enhance saltmarshes in places they currently occupy and enable their expansion with sea level rise, we actually might be able to expand the total area they currently occupy (Kirwan & Megonigal 2013, Geselbracht *et al.* 2015, Raposa et al. 2016, Cahoon et al. 2021). To understand this potential, we need to be able to model the potential expansion of saltmarsh ecosystems with sea level rise and the management actions that would help facilitate their adaptation to future conditions (Schuerch et al. 2018).

While there has been increasing research on the response of saltmarsh (often called tidal marshes internationally) to sea level rise, it is important to understand how saltmarsh species in Australia may respond to sea level rise and potential restoration actions (Raw et al. 2021). However, case studies of restoration and sea level rise modelling are spread across the literature and unpublished reports, and there is a need to synthesise this information to understand what the gaps in our knowledge are. In addition to understanding the potential for saltmarsh response to restoration and sea level rise, we also need to understand the legislative mechanisms and policy frameworks that can help facilitate saltmarsh restoration and management. However, both legislation and policy related to saltmarsh ecosystems are spread across multiple documents, and across different levels of government (eg. Federal, state), Traditional Owners (eg. Healthy country plans) and management agencies (eg. Catchment Management Authorities, Parks Victoria). Therefore, there is a need to conduct both a literature, and a legislative and policy review of saltmarshes in relation to restoration and sea level rise in Australia, with a focus on southern Australia.

In this study we undertook 1) a literature review and knowledge gap analysis of research on saltmarsh restoration and sea level rise in Australia, 2) a legislative and policy review of documents in relation to saltmarsh restoration and sea level rise, 3) using Swan Bay, Victoria as a case study, conducted a first-pass assessment of opportunities for saltmarsh restoration and management with sea level rise into the future, and 4) this was then ground-truthed to determine priority locations for action and further investigation.

Methods

Literature & Policy Review

To enable effective restoration and management of saltmarsh with sea level rise, it is important to understand both what research has been done on to date (i.e., a literature gap analysis) and the legislation and policy mechanisms which can enable any potential actions. Therefore, we conducted both a literature review of existing saltmarsh restoration and sea level rise research and a legislation and policy review.

Literature Search

For the Victorian literature review, the ISI Web of Science database and Google Scholar were utilised to source relevant literature. Each search query included one search term from each of the search categories: Ecosystem (1), Themes (2) and Location (3). The search terms for each search category are shown in Table 1. For example, one search query was “Saltmarsh*, Sea level rise, Victoria.” Search queries continued until all papers were captured from every combination of search terms from each search category.

Table 1. Search terms used to find relevant literature in the ISI Web of Science and Google Scholar. TS = Topic Search. ISI Web of Science searches for the term within the Title, Abstract, Author and Keywords of the publication record.

	Search category	**Search term**
1	Ecosystem	TS = Saltmarsh*, Salt marsh*, tidalmarsh*, tidal marsh*, coastal wetland*, mangrove*,
2	Themes	TS = Sea level rise, Sea-level rise, coastal retreat, migration, adaptation*, planning, restoration*, revegetation, protection, conservation, management, rehabilitation
3	Location	TS = Victoria, Port Phillip Bay, Western Port, Corner Inlet, Gippsland Lakes

This process resulted in 48 papers imported from Web of Science and 15 from Google Scholar. An additional 10 papers were imported from the subsequent Australian review (see below), resulting in a total of 73. From this set of literature, eight were removed due to duplication, 31 were deemed not relevant through title and abstract screening and 10 were removed after full text screening (nine due to wrong setting and one due to irrelevance). This resulted in a total of 24 Victorian relevant literature.

As the main reason for exclusion for the Victorian review was the study area and many non-Victorian papers were found to be relevant to this report, an Australian review was later conducted. This review followed the same methodology as the Victorian review, however the only search term for the search category 'Location' was 'Australia' and only the ISI Web of Science database was used.

This search resulted in 844 papers imported from Web of Science, and an additional nine papers were imported from the Victorian review, leading to a total of 853. 10 papers were removed due to duplication, 595 were deemed not relevant through title and abstract screening and 30 were removed after full text screening (13 due to wrong setting and 17 due to irrelevance), resulting in a total of 218 Australian relevant literature.

In order to understand the range and extent of pre-existing knowledge on saltmarsh restoration and coastal retreat, papers identified through the Victorian and Australian review were categorised by one or more of the following themes:

- Restoration response of plants
- Restoration biochemistry
- Planning, management or policy for plant restoration or protection
- Sea level rise response of plants
- Sea level rise geomorphology
- Planning, management, or policy for managing coastal retreat
- General plant ecology (not sea level rise or restoration)
- Other threats to plants

Policy Search

Policies and legislation for this review were sourced using the pre-existing knowledge of the authors and desktop research. Victorian and Australian legislation were sourced from the online Victorian Legislation registry and the Federal Register of Legislation respectively. Government department websites such as DELWP and regional catchment management authority websites were sources for information on state and local policy. Furthermore, key terms such as "saltmarsh," "sea level rise" and "restoration" along with "policy" and "legislation" were used in searches on Google. As some policies and legislation relate to environmental protection or advocate generally for environmental sustainability, only those which were directly related to Victorian saltmarsh restoration and coastal retreat were included.

First-pass assessment of saltmarsh migration

Spatial analysis

This study focused on the coastal saltmarshes of Swan Bay (Victoria, Australia; **Figure 1**), which provide an array of important ecosystem services to people, in addition to providing important habitat and food for unique and endangered species, the orange-belled parrot *Neophyma chrysogaster*. The largest threat to these migratory birds in the Swan Bay region is the loss of this crucial saltmarsh ecosystem. Unfortunately, there has been a history of saltmarsh loss and degradation around Swan Bay, and saltmarshes now also face potential impacts due to rising sea levels. For this study, we used a 2,000 m buffer to limit the study area (**Figure 1**).

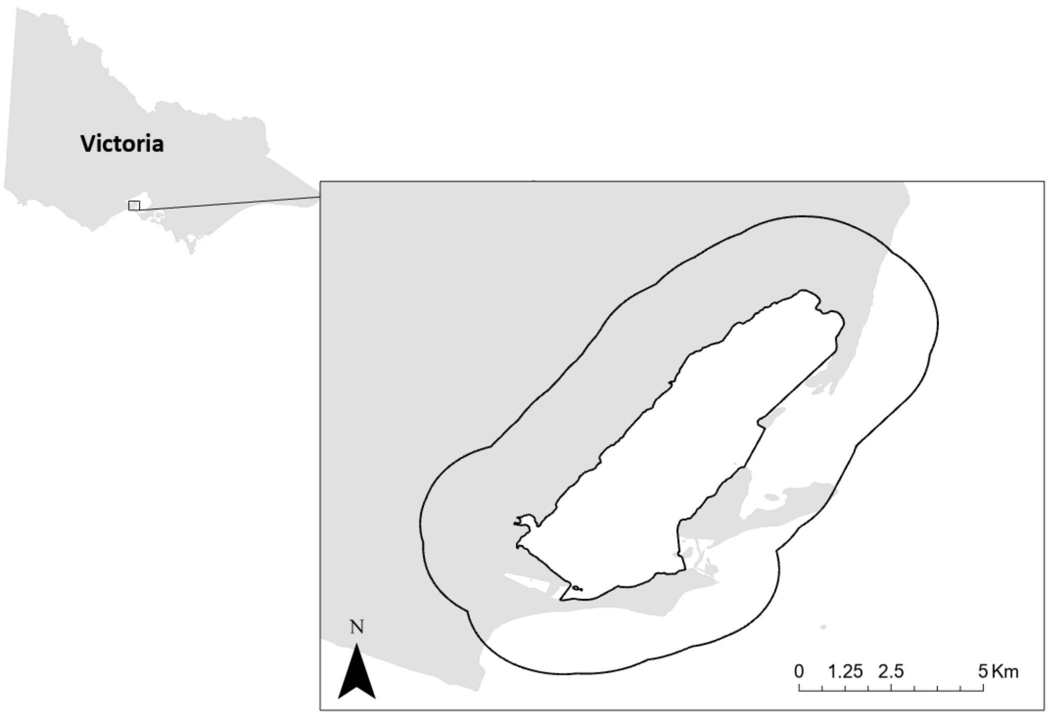


Figure 1: Swan Bay is located in Victoria (Australia) and is inhabited by the unique and endangered species orange-belled parrot *Neophyma chrysogaster*. For the purpose of this study, we used a 2,000 m buffer to limit the study area.

Understanding how restoration and future conditions may influence saltmarsh distribution is critically important in managing the orange-belled parrot, which tends to prefer wet saltmarshes (dominated mainly by *Sarcocornia quinqueflora* and *Tecticornia arbuscula*) as their habitats. In this study, we will build on previous studies conducted along Victoria's coastline (Gulliver et al., 2020; Moritsch et al., 2021; Costa et al., 2022) with the main assumption that elevation is the main driver of saltmarsh migration in recently inundated areas (Saintilan et al., 2013; Kelleway et al., 2017). We used existing datasets on historical and current distribution of saltmarshes (Boon et al., 2011), elevation (10 m; VCDM 2017), and state-based projections of sea level rise in 2040, 2070, and 2100 (DELWP, 2018) to develop a spatial assessment of potential saltmarsh migration at local scale. For that, we combined the elevation information to understand the elevation ranges that each saltmarsh Ecological Vegetation Class (EVC) in Swan Bay currently inhabit. Since multiple saltmarsh EVCs overlap in a relatively small region, we merged the EVCs into five classes: dry saltmarshes, coastal saltmarshes, dry scrub, estuarine grasslands, and wet saltmarshes (**Table 1**). We followed the approach developed by Gulliver et al. (2020) and used the existing saltmarsh distribution map (Boon et al., 2011) as a baseline layer to map potential saltmarsh migration under different management scenarios, such as levee removal, fencing and managed retreat. **Table 2** shows the details for each management option included in the study.

Table 2: Ecological Vegetation Classes identified in the current distribution of saltmarshes within Swan Bay.

Ecological Vegetation Class	Merged class
Coastal Dry Saltmarsh	Dry saltmarsh
Coastal Hypersaline Shrubland	Dry saltmarsh
Coastal Saltmarsh	Coastal saltmarsh
Coastal Saltmarsh - Saline Aquatic Meadow	Coastal saltmarsh
Coastal Tussock Saltmarsh	Dry saltmarsh
Coastal Tussock Saltmarsh - Coastal Hypersaline Shrubland	Dry saltmarsh
Coastal Tussock Saltmarsh - Wet Saltmarsh Herbland	Dry saltmarsh
Dry scrub	Dry scrub
Estuarine Flats Grassland	Estuarine grassland
Estuarine Flats Grassland - Estuarine Wetland	Estuarine grassland
Estuarine Wetland	Estuarine grassland
Saline Aquatic Meadow	Wet saltmarsh
Wet Saltmarsh Herbland	Wet saltmarsh
Wet Saltmarsh Herbland - Saline Aquatic Meadow	Wet saltmarsh
Wet Saltmarsh Shrubland	Wet saltmarsh
Wet Saltmarsh Shrubland - Coastal Tussock Saltmarsh	Wet saltmarsh
Wet Saltmarsh Shrubland - Wet Saltmarsh Herbland	Wet saltmarsh

Then, we modelled potential EVC classes suitable for migrating in new areas following each management action based on the elevation ranges they currently occur. We used the lower mean elevation value of each EVC to determine its threshold/break point. Furthermore, we estimated the area (ha) of each EVC, and potential area occupied following a management action.

This first-pass assessment is likely to inform future recommendations for on-ground projects, such as hydrological modelling at an individual restoration site-level. Spatial analyses were undertaken in ArcGIS Pro 2.4.3 and R.

Table 3: Description of each scenario, including rationale, methods, and assumptions, included in this study.

Scenario	Background, Methods & Assumptions
Fencing	Feral animals and livestock can impact the distribution of saltmarshes and the capacity of these ecosystems to provide ecosystem services. Furthermore, causing substantial erosion, preventing recruitment, and limiting the vegetation growth (Mihailou & Massaro, 2021; Waltham & Schaffer, 2021). Here, we identified areas suitable for restoration through fencing of collapsed saltmarshes that are currently being used as pasture and/or grazing lands. For that, we considered two scenarios: 1. Based on where saltmarshes existed historically, but do not exist in their current distribution. 2. Based on current distribution of saltmarshes that exist within pasture and grazing lands, assuming they are under poor conditions. We used the most recent land use cover data available for Victoria (Department of Environment Land Water and Planning 2018) and the pre-European and current distributions of saltmarshes (Boon et al. 2011). The main assumptions of this scenario are: 1. Installing a fence around the site perimeter would remove grazing and allow saltmarshes to recover over time. 2. A fence would be deployed in the entire site perimeter since we lack information on the locations of existing fences in Victoria.
Managed Retreat	Sea level is expected to trigger the loss of saltmarshes in some locations, it is also likely that it will represent an opportunity to restore and/or expand their distribution in newly inundated areas. Here, we used the 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 2018). We also assumed that collapsed saltmarshes (Boon et al. 2011) would be restored with the early signs of sea level rise in 2040, while also allowing for additional expansion of saltmarshes in areas inundated by sea level rise from 2070 and 2100 (Moritsch et al. 2021, Costa et al. 2022). For this scenario, we also assumed that no additional levees or sea wall fortifications were built to limit sea level rise inundation.
Fencing plus Managed Retreat	In this scenario, we combined the 'Fencing' and 'Managed Retreat' management options (including their assumptions) to identify areas that are likely to be inundated through sea level rise that are currently used for pasture and grazing.
Levee Removal	Restoration of saltmarshes through the removal of levees, and consequently, reintroduction of tidal flows, has been aligned with the first blue carbon method released in 2022 in Australia, which allows for the issuance of Australian Carbon Credit Units (ACCUs) (Clean Energy Regulator 2022). For that, our main assumptions were: 1. Return of tidal exchange will allow for the restoration of saltmarshes. 2. Areas suitable for restoration would be within 1 km of existing levees with elevation ranging from 0 to 1 m. Then, we assumed that current elevation would be decreased by 1 m to account for bathymetry works in the area (Gulliver et al., 2020). In this study, only one levee was identified within the study region based on our local knowledge of the region. A state-wide layer showing the mapped levees along Victoria's coastline was also used, however, there was no mapped levee in the region. It is important to highlight that this approach does not replace hydrodynamic modelling and site-specific analysis before undertaking a blue carbon project.

Field-validation

After the first-pass saltmarsh restoration and migration assessment was finalised, we conducted site visits to some of the sites identified through this process to understand the current condition of saltmarsh, the actions that could be undertaken to improve condition or extent of saltmarsh and if this matched with the areas and actions identified through the spatial assessment. Site visits were conducted between February-June 2022.

Key factors assessed as part of these site visits were:

1) Are livestock currently being grazed at this site? And if so, could fencing alone improve condition or extent?
2) Are there potential impediments to restoration actions not identified through assessment (i.e., A land-use not likely to be altered to support saltmarsh or artificial structures such as walls)

Figure 2. Blue Carbon Lab team conducting site inspection of site 3C, recording vegetation type, presence of livestock and taking RTK GPS point.

Results & Discussion

Literature & Policy Review

Legislation & Policy

Legislation and policy which concern saltmarsh restoration and coastal retreat are shown in **Table 4** and **Table 5** respectively. There were three main pieces of legislation which have direct implications for Victorian saltmarsh, one at the national level and two at the Victorian level. As for policies, there were seven in total, two at the national level and five at the state level. In addition, there were a total of 13 policy documents relevant to Victorian saltmarsh restoration and conservation found at the local Catchment Management Authority (CMA) level.

Legislation including the Environment Protection Act 2017, National Parks Act 1975, Catchment and Land Protection Act 1994, Planning and Environment Act 1987, and the Fisheries Act 1995 were considered in the review however were excluded due to protecting (through mechanisms including defining protected areas, penalties and punishments, pollution and waste management requirements, land management practices to protect from invasive species and sustainable fishing practices) rather than restoring Victorian saltmarsh. Similarly, policies such as the Victorian Invasive Plants and Animals Policy Framework and the Surf Coast Shire's Pest Plant and Animal Strategy 2020-2023 were also excluded for this reason.

Table 4. Coastal Retreat and Saltmarsh Restoration Policy and legislation. Information on legislation sourced from the Federal Register of Legislation and the Victorian Legislation registry. Only legislation with direct implications for Victorian Saltmarsh were included.

Jurisdiction	Legislation	Purpose	Implications for Victorian Saltmarsh
National	Environment Protection and Biodiversity Conservation Act 1999	The purpose of this Act is to provide a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities, and heritage places.	The act defines the process to identify Ramsar wetlands. It also establishes the Environment Protection and Biodiversity Conservation Regulations 2000 which outlines Australian Ramsar management principles including the need for environmental impact assessments, management plans, and public consultations on decisions which have a significant impact on the wetland and planning to promote conservation of listed wetlands.
Victoria	Marine and Coastal Act 2018	This Act's purpose is to provide an integrated and coordinated approach to planning and managing the marine and coastal environment.	Outlines guiding principles, establishes the Marine and Coastal Council (who provide independent advice on the Marine and Coastal Policy 2020 and Marine and Coastal Strategy 2022), establishes the Marine Spatial Planning framework, enhances local planning, and defines priorities for DELWP to build an understanding of coastal erosion and flooding.
Victoria	Flora and Fauna Guarantee Act 1988 (and Flora and Fauna Guarantee Amendment Act 2019)	The purpose of this Act is to provide a conservation management framework to conserve Victoria's native plants and animals.	Allows the secretary to determine an area of Victoria as a critical habitat and create management plans relating to its conservation, management, and restoration. Allows the minister to issue a habitat conservation order for the purposes of conserving, protecting, or managing critical habitats.

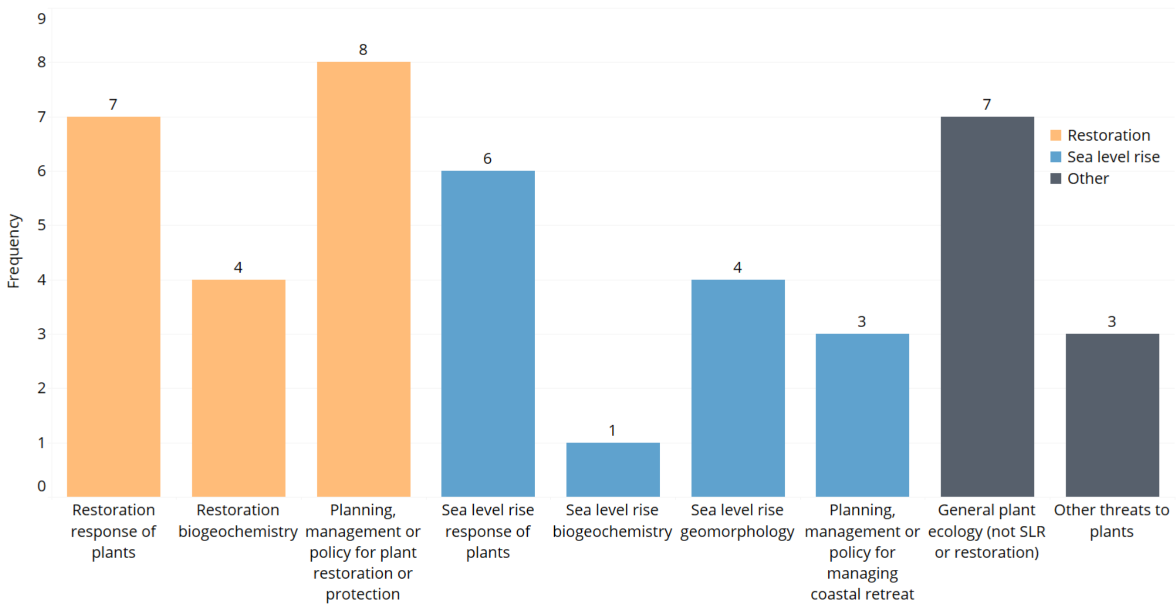
Table 5. Coastal Retreat and Saltmarsh Restoration Policy. Information on policy sourced from DELWP website and Coastal CMA policy from Regional Catchment Management Authority websites. Only policies with direct implications for Victorian Saltmarsh were included.

Jurisdiction	Policy	Purpose	Implications for Victorian Saltmarsh
National	Environment Restoration Fund	The purpose of this $100 million investment by the Australian Government is to support a range of activities that will improve environmental outcomes.	This policy provides finance to a range of coastal ecosystem protection and restoration projects including the protection and restoration of native plants, wildlife and coastal environments in the Corangamite Catchment Management Authority and improving conservation outcomes in the Otway's region.
National	Emissions Reduction Fund	The purpose of the Emissions Reduction Fund is to encourage organisations and individuals to reduce their emissions (or increase their carbon sinks) through subsidising eligible projects.	The Emissions Reduction Fund credits eligible blue carbon conservation projects that introduce tidal flows to help support coastal wetland ecosystems.
Victoria	Marine and Coastal Policy 2020	The purpose of this policy is to provide direction and guide decision makers in the planning, management, and sustainable use of our coastal and marine environment.	Encourages decision makers to protect and enhance the marine and coastal environment (including rehabilitation and restoration programs) and strengthen resilience to climate change (including restoring natural features to mitigate coastal hazard risk).
Victoria	Marine and Coastal Strategy 2022	The purpose of this strategy is to identify actions to achieve the vision and objectives of the Marine and Coastal Policy 2020.	Details specific activities, including identifying and mapping habitat linkages across public and private lands for future migration and restoration of marine and coastal habitats and applying economic and policy instruments to incentivise the restoration of blue carbon.
Victoria	Natural Environment Climate Change Adaptation Action Plan 2022-2026	The purpose of this Plan is to ensure climate change risks are considered by the Victorian Government in their own policies and operations, as well as creating an environment for communities, industries, non-government organisations and local governments to adapt to climate change.	Action plan involves DELWP identifying areas where natural assets (including wetlands) could migrate under sea-level rise, resulting in better planning and decision making.
Victoria	Victoria's biodiversity plan Biodiversity 2037	The purpose of this plan is to establish a long-term vision, goals and priorities to stop the decline of native plants and animals and improve our natural environment.	Targets in the plan include revegetation in priority areas, increased permanent protection on private land and an overall net gain in the overall extent and condition of habitats across terrestrial, waterway and marine environments. The plan also defines enabling actions including taking a cost-benefit approach to waterway and marine management.
Victoria	Victoria's Marine and Coastal Reforms Final Transition Plan	The purpose of this plan is to establish a program of policy reforms and on-the-ground actions to transition to the new system Marine and Coastal system (including the Marine and Coastal Act 2018).	Plan details policy, practical actions, and other measures which have implications for Victorian saltmarsh including improving the monitoring of erosion and coastal flooding, restoring near-shore habitats at priority locations, and establishing a coastal asset database and investing in assets at critical risk.
Coastal CMAs:	Regional Catchment, Waterway and Climate Change Strategies.	The common purpose across these documents is to outline management and planning strategies to support local ecosystems, including saltmarsh.	Strategies detail ecosystem threats, priority areas, specific management actions and climate change mitigation and adaptation options, including habitat restoration and planning for sea level rise.

Literature Search

This literature review reveals that the state of pre-existing knowledge on saltmarsh restoration and sea level rise in Victoria is low with only 24 papers found. Of these papers, there appears to be a relatively similar level of research between restoration and sea level rise, however there is clearly more research concerning restoration biochemistry and planning, management or policy compared to the same sea level rise theme counterparts. The high restoration biochemistry literature count is explained by the ongoing blue carbon research conducted by Deakin University's Blue Carbon Lab, with all four papers led or co-authored by one or more Blue Carbon Lab researchers (Carnell et al. 2022; Gulliver et al 2020; Moritsch et al. 2021; Waryszak et al. 2021).

A)



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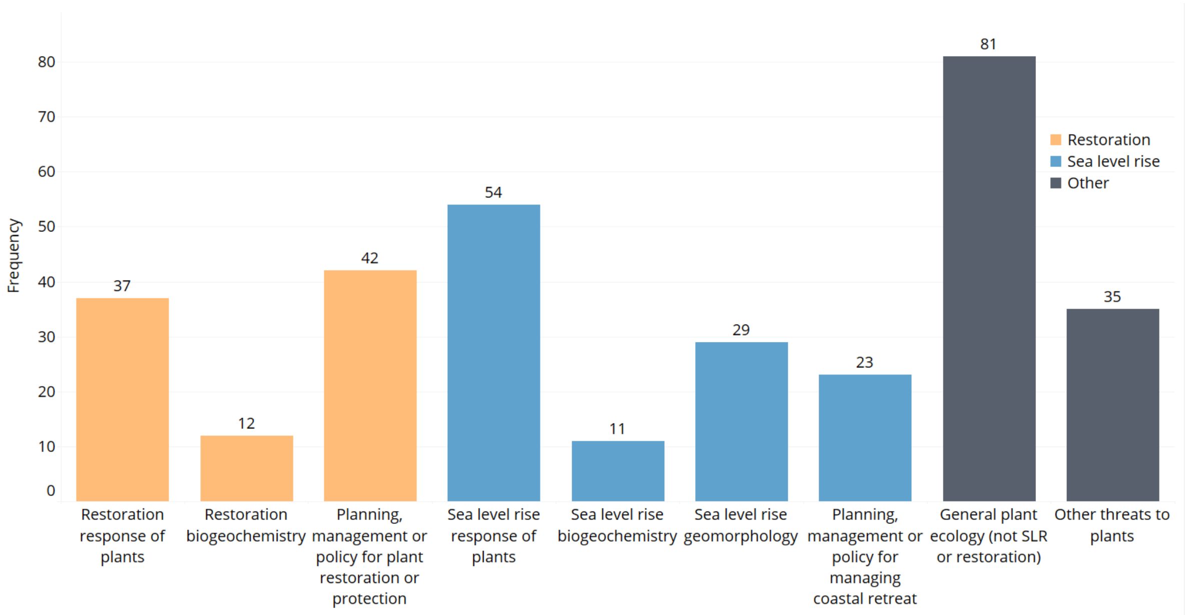


Figure 3. a) Frequency of Themes in Victorian Review (n=24) **b)** Frequency of Themes in Australian Review (n=218). Papers with multiple/overlapping themes are categorised in multiple categories.

Extending our search to all Australian studies increases the amount of literature captured from 24 in the Victorian review to 218 in the Australian review. Although studies were not categorised by state, this over 9-fold increase illustrates the lack of research in Victoria compared to the rest of the country, despite being endowed with approximately 33053 hectares of saltmarsh and mangroves (Sinclair & Boon, 2012). The distribution of themes in the Australian review compared with the Victorian review however is remarkably similar. For example, 54 out of the 218 (24.8%) papers in the Australian review were related to the sea level rise response of plants, compared to 6 out of 24 (25%) in the Victorian review. The largest differences in theme composition across the reviews are in the 'restoration' and 'other' categories. For example, 37 out of the 218 (17%) papers in the Australian review were related to restoration response of plants, compared to 7 out of 24 (29.2%) in the Victorian review. Additionally, 81 out of the 218 (37.2%) papers in the Australian review were related to restoration response of plants, compared to 7 out of 24 (29.2%) in the Victorian review. The 'other' category in the Australian review consisted of studies relating to general biochemistry (n=19), identification of and response from threats such as pollution and invasive vegetation (n=24), land cover detection (n=20) and Holocene distribution change (n=5).

Saltmarsh distribution and potential migration under different management options

Overall, the study region is home to approximately 480 ha of saltmarshes. From this total, most of the saltmarshes are classified as wet saltmarshes (~276 ha), followed by coastal saltmarshes (~107 ha) and dry saltmarshes (~73 ha) (**Figure 4**). By assuming that elevation is the main driver of saltmarsh distribution, **Table 6** shows the potential transition points between different EVC groups based on the existing elevation layer. We found that the coastal and wet saltmarshes nearly overlap, with elevation transition points varying from -0.73 m to -0.62 m, respectively (**Table 6** and **Figure 5**). Other EVC groups showed larger elevation ranges among them, indicating suitable elevations for their survival (**Table 6** and **Figure 5**).

Table 6: Elevation (in meters; minimum, maximum, mean, STD and median values) for each merged Ecological Vegetation Class (EVC) included in the study. We used the lower mean elevation value of each EVC to determine its threshold/break point.

Merged EVC class	Min	Max	Mean	STD	Median
Coastal saltmarsh	-0.72726	3.785	0.608338	0.285751	0.5375
Wet saltmarsh	-0.616961	2.015	0.481436	0.237544	0.4325
Dry saltmarsh	-0.418554	4.875	0.713703	0.299174	0.69
Estuarine grassland	-0.165	2.11	0.750285	0.285173	0.6975
Dry scrub	0.065	1.6325	1.011868	0.244058	1.045

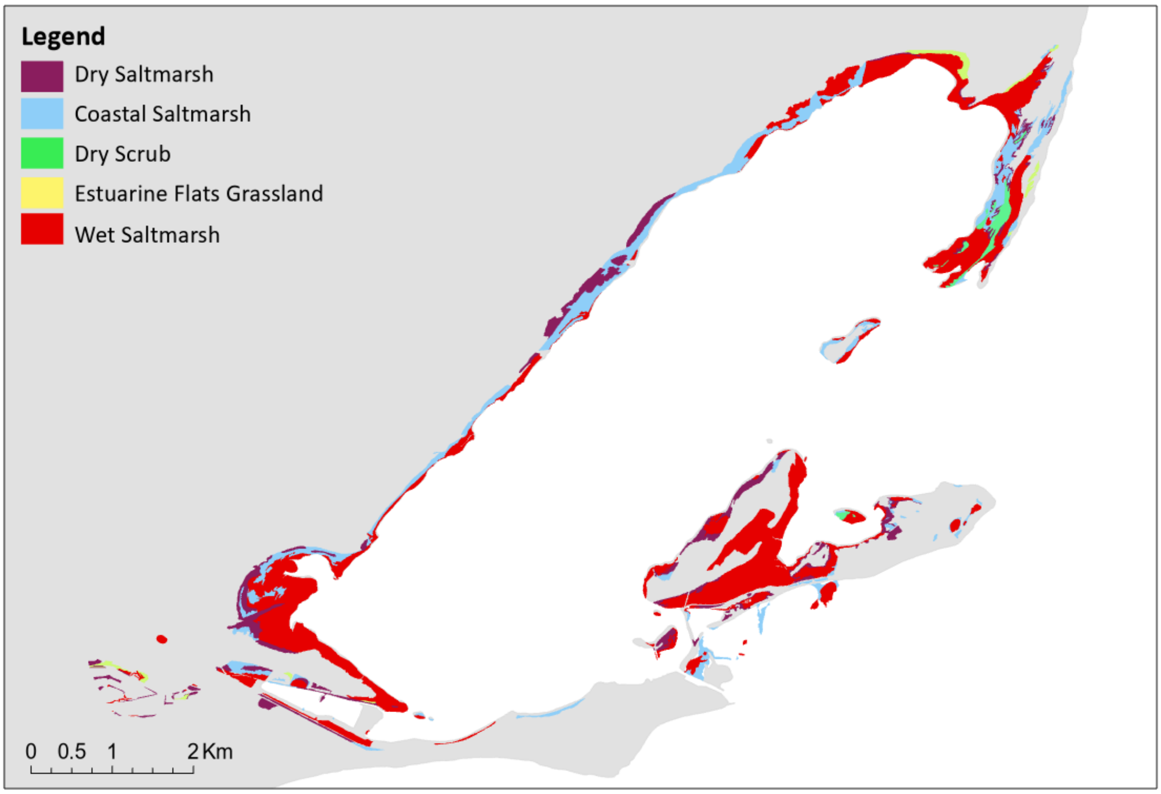


Figure 4: Mapped saltmarsh distribution for each ecological vegetation class (Boon et al., 2011), which were merged in five main classes based on their similarities: dry saltmarsh, coastal saltmarsh, dry scrub, estuarine flats grassland, and wet saltmarsh.

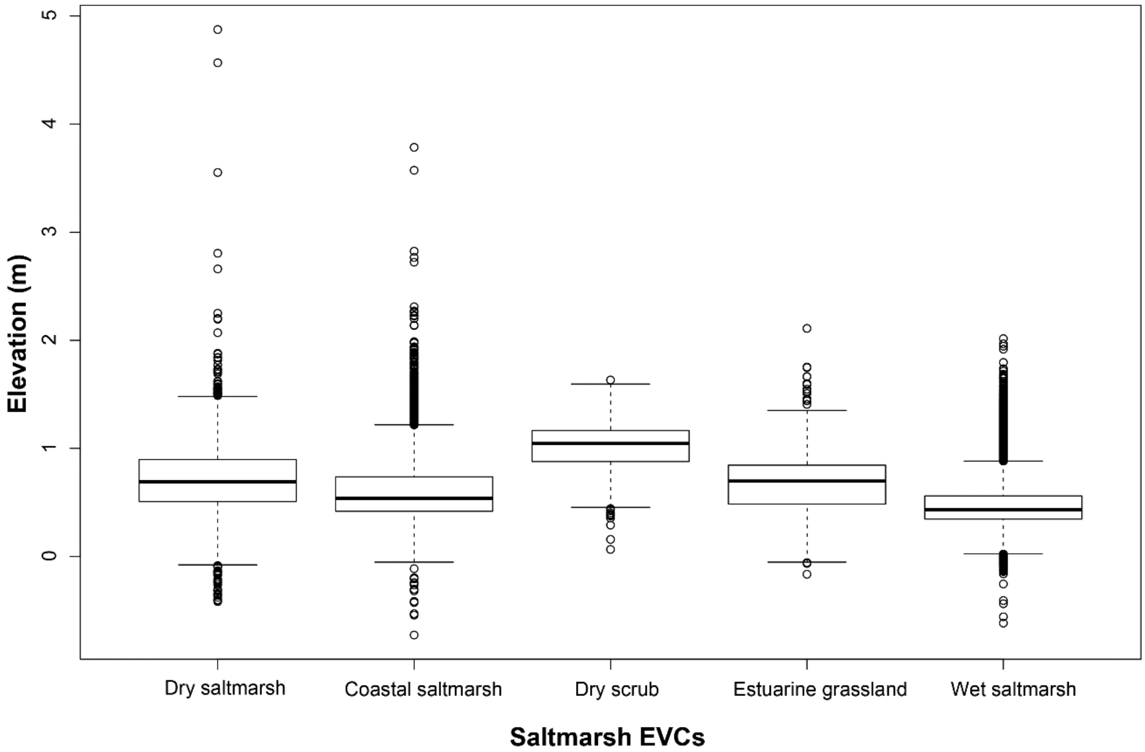


Figure 5: Boxplots showing the elevation (VCDM, 2017) data identified within each merged Ecological Vegetation Class (EVC) included in the study.

In this study, we evaluated the potential response from saltmarshes to different management options (**Figure 6**). The total area available for saltmarsh migration and restoration varies substantially based on the management action tested. Our analysis showed that planning for future inundation due to sea level rise (i.e., managed retreat) is key to restoring collapsed saltmarshes and potentially expanding their distribution in the region (**Figure 6** and **Table 7**). For example, early signs of sea level rise in 2040 is likely to represent a great opportunity for restoring wet saltmarshes in the region (**Figure 6** and **Table 7**). The scale of opportunities increases if we incorporate late signs of sea level rise in 2070 and 2100.

Furthermore, restoration through fencing also provides an opportunity to restore dry scrub saltmarshes in the region (**Figure 6** and **Table 7**). In this case, restoring collapsing saltmarshes would represent an opportunity of approximately 14 ha within the region, while rehabilitating existing saltmarshes within pasture lands could represent an opportunity of ~64 ha (**Table 7**).

Tidal re-instatement is currently the only blue carbon method under the Emissions Reduction Fund, with only one property within the region potentially eligible for registering a blue carbon project in Swan Bay (**Figure 6**). In this case, 21 ha would potentially be available for saltmarsh restoration, with greater contributions for estuarine grassland (7.4 ha) and dry scrub (8.8) saltmarshes (**Table 7**).

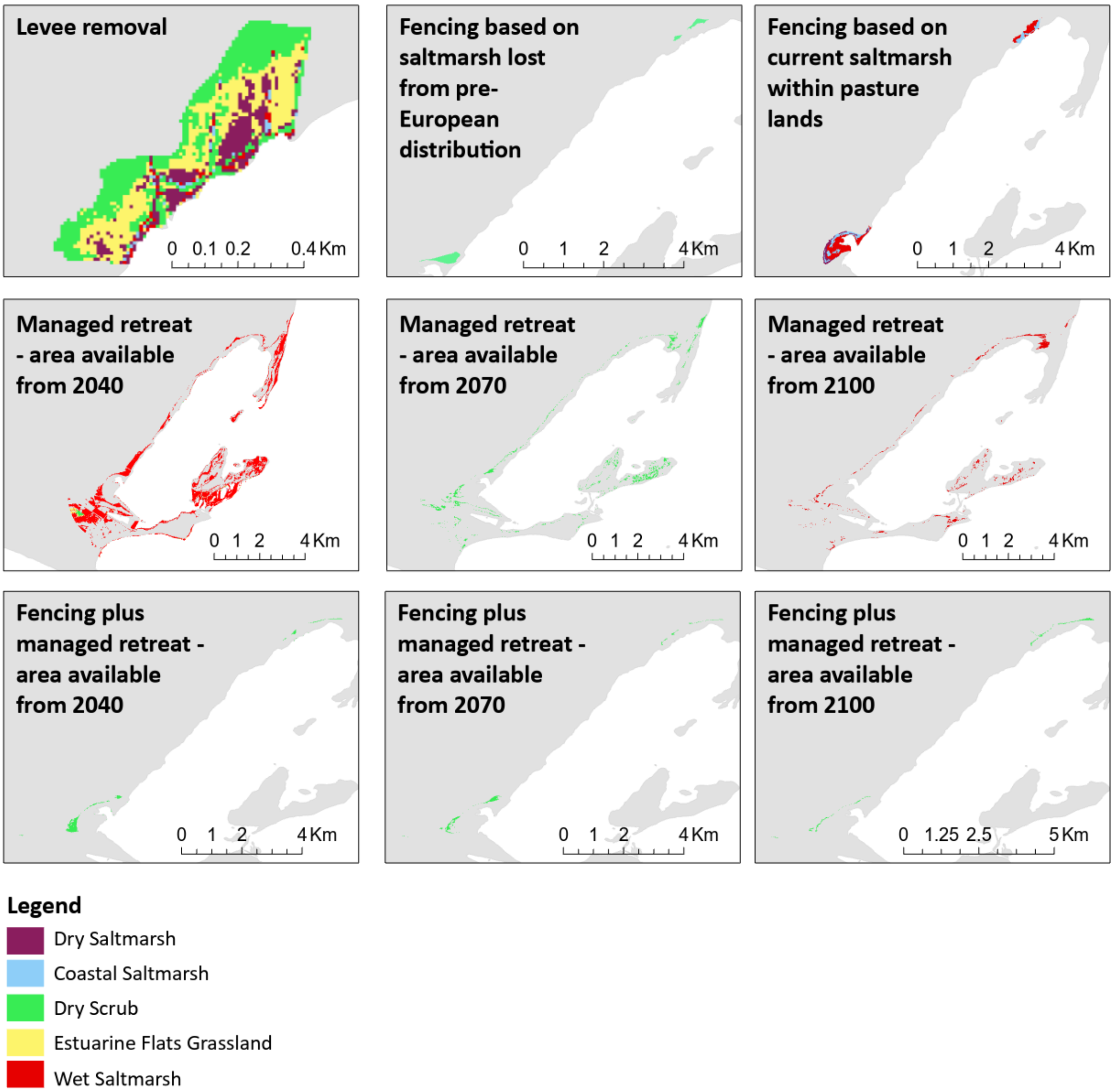


Figure 6: Detailed maps showing the potential area available for restoration within Swan Bay through different management actions.

Table 7: Area (ha) available for saltmarsh restoration under different management options. Notes: * values indicate areas available for restoration based on the past distribution of saltmarshes. **values indicate areas available for restoration based on the current distribution that occur within pasture and grazing lands, respectively.

Merged EVC class	Fencing	Managed Retreat	Fencing plus Managed Retreat	Levee Removal
Coastal saltmarsh	19**	0.63 (2040) 0.01 (2070) 0.003 (2100)	-	0.39
Wet saltmarsh	36.2**	461.7 (2040) 62.6 (2100)	-	0.56
Dry saltmarsh	8.5**	1.07 (2040) 0.04 (2070) 0.02 (2100)	-	3.7
Estuarine grassland	-	11.4 (2040) 0.15 (2070) 0.13 (2100)	-	7.4
Dry scrub	13.6*	5.3 (2040) 84.1 (2070) 0.05 (2100)	14.5 (2040) 9.5 (2070) 7.6 (2100)	8.8
Total (ha)	**13.6* 63.6****	**480 (2040) 84.3 (2070) 62.8 (2100)**	**As above**	**21**

Restoration feasibility assessment

We visited some of the most promising sites identified through our first-pass assessment, but also some additional sites through our own local knowledge to assess their potential for saltmarsh restoration. The sites are described individually below and identified in **Figure 7**.

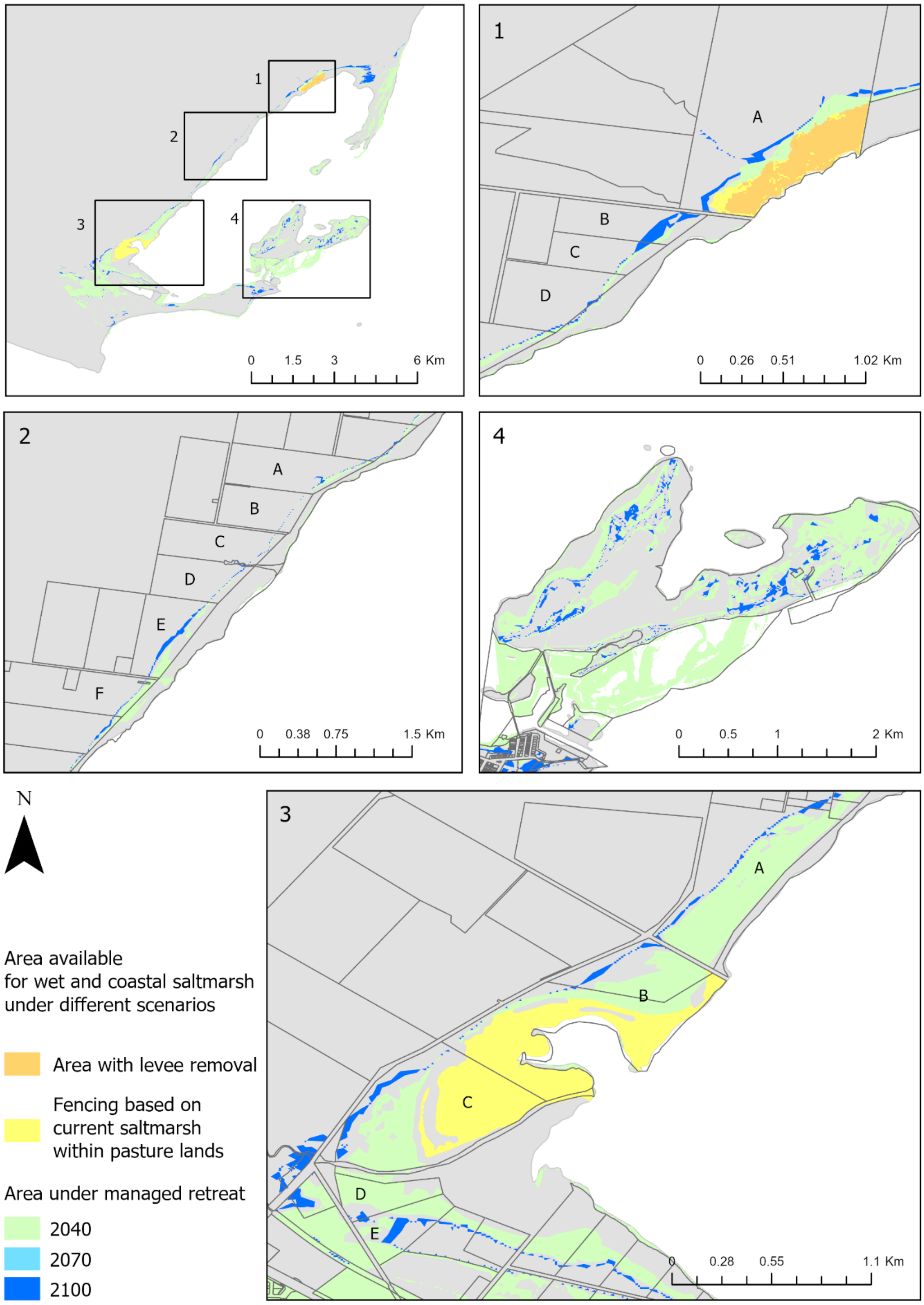


Figure 7. Wet saltmarsh restoration sites identified through the spatial assessment of the various management options now (levee removal and fencing) and into the future through managed retreat. The property boundaries are shown to help identify landowners and labeled according to a unique numbering system.

Site 1A

This site is the only site identified as having a bund wall and drainage in place which could be removed and filled to reinstate natural tidal flow to the site, which would improve saltmarsh condition across 16.8 ha (**Figure 8**). In addition, fencing could also be installed at the landward to edge to protect from livestock grazing both now (for a total of 20.8 ha with this area overlapping the area affected by bund wall), and into the future with managed retreat by 2040 (5.5 ha), 2070 (1 ha) and 2100 (2 ha). This site represents one of four large sites for saltmarsh rehabilitation actions and should be followed up as a priority.

Site 1B

This site has already had saltmarsh rehabilitation works conducted on it, with a fence installed roughly 12 years ago, which has seen substantial saltmarsh recovery (**Figure 8**), but also allows room for saltmarsh migration until 2100. No further saltmarsh rehabilitation works are recommended for this site.

Site 1C & 1D

Based on the spatial assessment, these two sites only had small potential for saltmarsh migration in the future. However, the site visit revealed roughly 3.1 ha of saltmarsh that could be fenced which would see rehabilitation of wet saltmarsh and enable future migration with sea level rise (**Figure 8**).

Figure 8. Sites from Region 1, a) Site 1A, showing the bund wall (foreground), channel and current *Sarcocornia quinqueflora* and coastal Tussock EVC saltmarsh. b) Showing site 1B on the left which was fenced ~12 years ago, and site 1C on the right with current disturbance from livestock grazing, c) Site 1 C and 1D as shown from aerial images. The foreground is the saltmarsh in Parks Victoria managed land, and behind it the private property with livestock grazing impacts.

A)

B)

C)

Site 2A

Saltmarsh rehabilitation has already occurred at this site, with all livestock excluded ~15 years ago when the new property owners began restoring the terrestrial landscape. With the removal of livestock, the saltmarsh in this area is already in the process of recovery (**Figure 9a**). Given the impressive landscape restoration actions occurring at this property, it is well positioned to facilitate migration into the future.

Site 2B

As we showed thorough our spatial assessment, there is already saltmarsh present (predominantly dry saltmarsh (coastal tussock saltmarsh EVC)), with the section predicted for saltmarsh migration already fenced at the top of the natural rise that would prevent saltmarsh migrating any further. The site visit confirmed this (**Figure 9b**), therefore there are no immediate actions recommended at this site.

Site 2C

This area was mapped as saltmarsh in 2014, and thus little area for potential restoration now and into the future (**Figure 7**). However, the site visit revealed that while there is coastal tussock saltmarsh EVC, this is impacted from livestock and thus fencing or other livestock exclusion methods would rehabilitate saltmarsh now and into the future (**Figure 9c** and **Figure 9d**).

Site 2D

We did not assess this site on the ground given its relatively low area of saltmarsh restoration potential based on the spatial assessment. However, we did assess this site using high resolution aerial imagery and it could be worth following up to see if removing livestock access via fencing might improve current saltmarsh condition and enable wet saltmarsh migration into the future.

Site 2E

The spatial assessment suggested a range of potential areas for saltmarsh restoration into the future (**Figure 9e**). The site visit showed that both the current saltmarsh is in a semi-degraded state, being impacted by disturbance from visitors to the caravan park and that restoration actions in the southern section of this site would be difficult unless access by people was excluded. However, there may be opportunity to work with the caravan park to turn this into a feature (e.g., Wetland boardwalk). The saltmarsh in the northern section of this property is in good condition and additional works may encourage saltmarsh migration potential into the future.

Site 2F

This site has recently been fenced via a partnership with the Deakin University's Blue Carbon Lab, Bellarine Landcare, and the Bellarine Catchment Network, in consultation with the landowner and funded by the Port Phillip Bay fund. This funded fencing of approximately 2 ha of saltmarsh, which occurred at the end of 2021 (**Figure 9f**).

Figure 9. Photos from the site visits to sites in Swan Bay region 2. **A)** Site 2B, showing the saltmarsh that has recovered since livestock has been removed ~15 years ago. **B)** Shows relatively healthy coastal tussock saltmarsh EVC, with fencing on the top of the ridge-line. **C)** Site 2C showing the area below the ridge-line that could be protected now and into the future through reducing access by livestock via fencing. **D)** The southern end of site 2C is shown here, with the ridgeline in the background. **E)** Site 2e is shown here, with the caravan park at the southern end of the boundary, which would impede any potential saltmarsh restoration or managed retreat options. **F)** Site 2F showing the recently installed fence to rehabilitate 2 ha of saltmarsh via a recently funded Port Phillip Bay Fund project.

A)

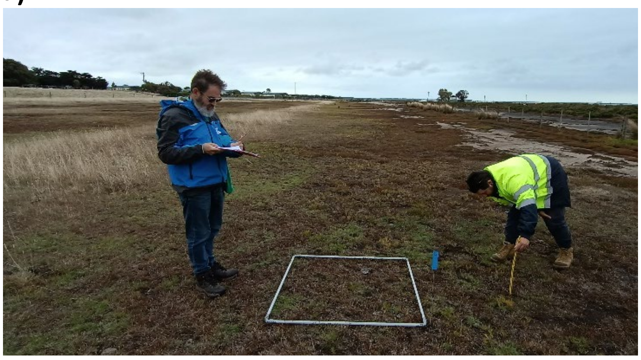
B)

C)

D)

E)

F)



Site 3A

This site was not identified for restoration through the existing data (was mapped as existing saltmarsh), but was identified for managed retreat in 2040 (18 ha), 2070 (0 ha) and 2100 (1 ha). However, the site visit revealed that this site is also a candidate for fencing to restore and improve the condition of saltmarsh currently present (**Figure 10**a). This presents an ideal site for restoration actions both now and into the future, and forms part of a cluster of sites in the south-west of Swan Bay, which is restored and managed, could represent a significant combined area of healthy and restored saltmarsh, now and into the future (**Figure 7**).

Site 3B

In the south-west corner of Swan Bay, there is a large area that was previously saltmarsh that could be restored through fencing (**Figure 10b**). In addition, this site was also identified as an area that could see additional saltmarsh restoration into the future through managed retreat in from 2040-2100 (**Figure 7**). With these actions combined, there is a total area of 12 ha available for saltmarsh restoration (**Table 8**), now and into the future.

Site 3C

This site was identified as a large area of existing saltmarsh, which is currently on land designated as grazing/agriculture. Through discussions with the landowner, we have discovered that this land has not been grazed for approximately 60 years, and is in relatively good condition (**Figure 10c**). Despite this, developing a strong relationship with the landowner and developing more site-specific management plans to ensure all threats are managed and all options to enable managed retreat are investigated is still important at this site.

Site 3D

This site presents an opportunity to facilitate saltmarsh migration with sea level rise, with parts of the land currently used for livestock grazing. Fortunately, the current landowner has recently undertaken some fencing to try and rehabilitate the saltmarsh, with encouraging signs (**Figure 10d**). This site should be considered for further saltmarsh rehabilitation and migration actions.

Site 3E

The site currently has livestock grazing and is a great opportunity for saltmarsh restoration, in an area that is likely to be currently occupied by coastal tussock saltmarsh EVC. However, restoration actions now, could see this become an area for wet saltmarsh migration into the future, with 3.6 ha by 2040 and an extra 1 ha by 2100 (**Figure 10e**, Table 8).

Figure 10. Photos from site visits to region 3. **A)** Site 3A, which was identified as having large potential for restoration with managed retreat by 2040, has areas where fencing could benefit wet saltmarsh now (foreground). **B)** Site 3B is a large site, which has potential for managed retreat to enable large area of saltmarsh migration by 2040 (left of image). There is existing fencing protecting the large area of good condition saltmarsh (right), and a new fence which has been installed in a zone which could see wet saltmarsh migration by 2040. **C)** Site 3C has not been grazed for ~60 years, and in good condition. **D)** Fencing at site 3D could see recovery of coastal tussock saltmarsh**,** but with the spatial assessment showing this area could be wet saltmarsh by 2040. **E)** Site 3E is currently being grazed, so livestock management now and into the future would improve current saltmarsh condition of coastal tussock EVC, which could be wet saltmarsh by 2040.

A)

B)

C)

D)

E)

Site 4

Swan Island has been cleared of saltmarsh in a number of areas to allow for the Queenscliff Golf Course and the Australian Defence Force army base. While the areas fenced off are in good condition (**Figure 11a**), the proximity of both to the water line (**Figure 11b**) and land use that is unlikely to change, means there are relatively limited current opportunities for saltmarsh rehabilitation actions on Swan Island.

Figure 11. Sites where current land use makes restoration or sea level rise planning difficult. At the Queenscliff Golf Course (site 3), much of the area identified for wet saltmarsh migration by 2040 are current golf holes **(A)** and **(B)**, making any saltmarsh rehabilitation actions difficult without changes to the course. **C)** There are also large areas identified for wet saltmarsh migration by 2040 in the area which is currently under development by the housing development known as “The Point”.

A)

B)

C)

Table 8. Description of area available under the different restoration scenarios at the sites that were inspected as part of the feasibility assessments. * denotes sites where there was more area available for restoration as determined by the site assessment compared to the spatial assessment.

Property site code	Current saltmarsh to be protected with fencing (ha)	Area with levee removal (ha)	Managed retreat 2040 (ha)	Managed retreat 2070 (ha)	Managed retreat 2100 (ha)	Total wet/coastal saltmarsh area that could be restored on site (ha)
1A	16.8	14.7	5.5	0	2.0	39.0
1B			0.4	0	1.4	1.8
1C	2.2* (0)		0.3	0	0.3	2.8* (0.6)
1D	0.9* (0)		0.3	0	0.2	1.4* (0.5)
2A			1.1	0	0.3	1.5
2B			0.1	0	0.1	0.2
2C			0.1	0	0.1	0.2
2D			0.2	0	0.2	0.4
2E			2.8	0	1.7	4.5
2F			2.1	0	0.2	2.3
3A			17.9	0	0.8	18.7
3B	22.8		12.0	0	0.7	35.6
3C	14.8		9.2	0	1.5	25.5
3D			5.0	0	0.1	5.1
3E			3.6	0	1.0	4.6
TOTAL AREA	**57.5**	**14.7**	**60.6**	**0**	**10.6**	**143.6**

Conclusions & Recommendations

This project has shown the power of combining a spatial assessment of current and future saltmarsh rehabilitation opportunities, with on-ground site feasibility assessments. Here we have shown there are both small (1-5 ha) and large (>20 ha) opportunities for saltmarsh restoration now and into the future. However, given that most of these opportunities are on private land, relationships and collaborations with local landowners will be key to any actions on these sites. However, through the site visits we made, many of the local landowners are receptive, and indeed have been proactive in already conducting some form of saltmarsh rehabilitation or protection works (sites 1B, 2A, 2B, 2F, 3B, 3C, 3D). With a growing interest in saltmarsh restoration for both their biodiversity and carbon sequestration benefits (Macreadie et al. 2022, Lovelock et al. 2022), Swan Bay represents a region where on-ground actions can have wide ranging benefits.

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