Climate Change Vulnerability Assessment and Adaptive Capacity of Coastal Wetlands

Decision Support Framework – Volume Two

Environment, Land, Water and Planning

Acknowledgements

The authors would like to thank the Steering Committee who oversaw the work of this project and provided valuable input: Mark Rodrique, Parks Victoria, Rex Candy, East Gippsland Catchment Management Authority, Eleisha Keogh and Matt Khoury, West Gippsland Catchment Management Authority, Andrew Morrison, Port Phillip and Westernport Catchment Management Authority, Donna Smithyman, Corangamite Catchment Management Authority, Jacinta Hendricks, Glenelg Hopkins Catchment Management Authority, Andrea White and Janet Holmes, DELWP. Andrea White provided comments on the draft and final reports.

Authors

Heard, S., Treadwell, S. and Boon, P

Citation

Department of Environment, Land, Water and Planning (2016). Climate change vulnerability and adaptive capacity of coastal wetlands. Decision Support Framework – Volume Two. Department of Environment, Land, Water and Planning, East Melbourne, Victoria.

Photo credit

Tim Allen

ISBN 978-1-76047-427-0 (pdf/online)

Report produced by

Jacobs Group Australia

Level 11 452 Flinders Street Melbourne VIC 3000

Web: www.jacobs..com

Accessibility

If you would like to receive this publication in an alternative format, please telephone the DELWP Customer Service Centre on 136186, email customer.service@delwp.vic.gov.au, or via the National Relay Service on 133 677 www.relayservice.com.au. This document is also available on the internet at www.delwp.vic.gov.au.

Contents

1. Introduction

1.1 Background

This document is the second volume of a two-volume set that presents a Decision Support Framework (DSF) for assessing the vulnerability and adaptive capacity of coastal wetlands in Victoria. Volume One provided a step-by-step process for wetland managers to follow when applying the DSF. Volume One also provided a case study using the Powlett River in South Gippsland. Volume Two (this report) presents the technical information that supports the framework. The logic and assumptions underpinning the DSF are formulated as a series of questions aligned to the project objectives:

- What are 'coastal wetlands'?
- What is climate change and how will it impact coastal wetlands?
- How sensitive are different types of coastal wetland to the various components of climate change and what is their adaptive capacity?
- What are the management options, in terms of general strategies and in terms of specific management options?

1.2 Vulnerability assessment framework

The vulnerability assessment aims to determine the vulnerability and adaptive capacity of wetlands in Victoria to the impacts of climate change. The evaluation is made using a risk based approach (Figure 1), which centres on a joint assessment of ***exposure*** of a given suite of wetlands to the impacts associated with specific components of climate change and the ***sensitivity*** of wetland values to these threats. These two elements are equivalent to 'likelihood' and 'consequence' in a traditional risk assessment approach consistent with the Australian Standard for risk assessments (AS/NZS ISO 31000:2009, Risk management - Principles and guidelines). In combination, they define the ***potential impact*** (or level of risk). When potential impact is linked with ***adaptive capacity*** (either autonomous or by intervention) it is possible to make an assessment of the ***vulnerability*** (residual risk) of wetlands to the potential impacts of climate change.

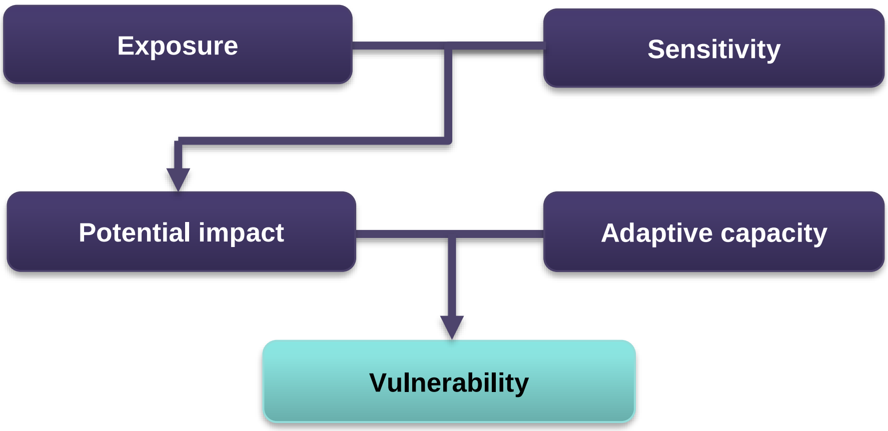


Figure 1: Assessment approach to determine the vulnerability and adaptive capacity of wetlands in Victoria to the impacts of climate change

Section 2.1 in Volume One provides definitions of each of the vulnerability assessment components in the context of this project. Each component is explored in further detail in later sections of this Volume.

1.3 Decision Support Framework

The broad approach applied in the DSF is illustrated in Figure 2. The DSF is a three step approach that is closely aligned with the project objectives. The subsequent chapters in the report are arranged to help the user work through the DSF. The three steps are as follows:

- **Step 1: Wetland type** – identification of wetland type (e.g. mangrove, saltmarsh) using a combination of the coastal wetland dataset developed as part of this project and existing knowledge of the site. This step guides the sensitivity assessment undertaken in step 2.
- **Step 2: Assess potential impacts from climate change** – based on the position of the wetland in the landscape, identification of which component of climate change the wetland is sensitive to. This step involves undertaking the exposure and sensitivity components of the vulnerability assessment outlined above using a combination of the exposure mapping, conceptual models and sensitivity tables provided in this report.
- **Step 3: Identify management objectives and actions** – identification of the adaptation mechanisms possible for the wetland and development of management objectives and actions. This step will inform the development of a management plan which is undertaken outside of the DSF.

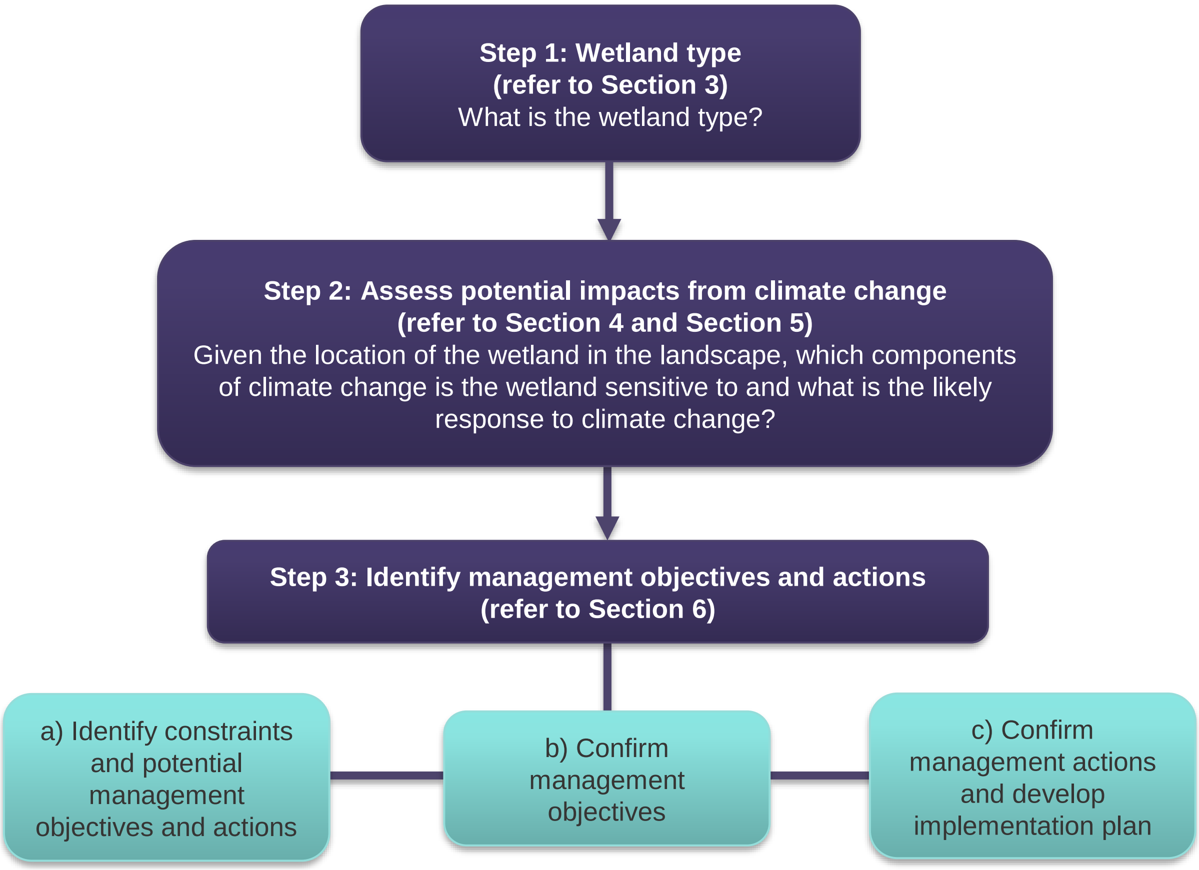


Figure 2: Decision Support Framework outlining the key steps for assessing the vulnerability and adaptive capacity of coastal wetlands to climate change components

Section 2.2 in Volume One presents more detail on the DSF and the methods applied for assessing the vulnerability and adaptive capacity assessment.

1.4 Volume Two Report

This report (Volume Two) provides detailed technical information that supports the application of the DSF and describes the logic and assumptions behind each of the considerations underpinning it. The report provides the technical information to support wetland managers who have to manage different types of coastal wetlands under climate change. Management objectives and actions are also explored in this report.

The structure of this report is as follows:

- Section 2 – describes the approach undertaken to classify coastal wetlands and describes the key types of wetlands found in the coastal zone.

- Section 3 – provides a summary of climate change in the coastal context, including the different components of climate change and their likely impacts on coastal wetlands in Victoria. It also outlines the climate change projections available for the coastal zone and the approach undertaken to define and map exposure of coastal wetlands in Victoria to climate change.
- Section 4 – combines wetland types found along the Victorian coastal zone and their position in the coastal zone to determine how sensitive and adaptive they are to the components of climate change. Conceptual models are presented in this section to help describe the likely response of coastal wetlands to the different climate change components along with tables ranking the sensitivity of each wetland type to the climate change components for use in the DSF. It also provides a discussion around the adaptive capacity of coastal wetlands to climate change and how this may be assessed and how wetland values are considered within the vulnerability assessment and DSF.
- Section 5 – describes the different management options available for coastal wetlands to adapt to climate change. It includes guidance on identifying constraints to management, setting management objectives and identifying the suitable management actions to achieve the objective.
- Section 6 – makes conclusions on the applicability of the DSF and methods, and makes recommendations for future use and improvements.

2. What are coastal wetlands?

The following sections provide a summary of the approach to defining coastal wetlands. A detailed discussion supporting the definitions is provided in Appendix A.

2.1 Definition of the term 'coastal'

The words 'coastal' or 'coastal zone', although widely used in many contexts for management, geomorphological, ecological and demographic investigations, are rarely defined consistently or unequivocally. Two problems are apparent. First, often the spatial delimitation is simply left undefined, with the expectation that readers implicitly know what 'coastal' means and where the coastal zone ends and the non-coastal or inland zone starts (e.g. Lazarow *et al* 2006; National Resource Management Ministerial Council 2006). This vagueness is problematic, as it is not clear what parts of the landscape are considered within scope and what parts are out of scope.

The second problem is that different disciplines take 'coastal' to mean different things. The United Nations Food and Agriculture Organisation (2012) also notes the term means different things according to whether the topic of interest is management, demographics, geography or ecosystem dynamics[1]. Demographers, geomorphologists, ecologists and coastal-zone managers are likely to have quite different understandings of the term 'coastal'. This variation presents a dilemma for the current project, as all four groups will have some interest in the effect and management of climate change on Victorian coastal wetlands.

An analysis of the various approaches to defining 'coastal' (see Appendix A) shows there is no single compelling operational definition of what the word means. The variance in definitions should not be seen as an insurmountable issue. The Nairobi Convention on the coastal zone advised that it was not possible to devise a precise boundary for the coastal zone and that flexibility was required according to the aims of the investigation or management plan:

> *'Its precise delimitation depends directly on the problem posed initially. The limits should therefore extend into the sea and land just as far as required by the objectives of the management plan'*[2].

Even so, for the purposes of the current project it is necessary to define operationally what is meant by the term 'coastal'. The definition of 'coastal' adopted for the project is that the coastal zone is ***the area around the shoreline of Victoria between 0 and 10 m AHD***. This definition has a number of desirable features. It is short and simple, spatially explicit and easily applied with existing information. It can be applied to the entire Victorian coast, captures areas that experience a strong marine influence and all other 'coastal' systems that are likely to be impacted by climate change (e.g. coastal floodplains and dune systems). Section 2.4 outlines this diversity of wetland types and the subdivisions necessary for all to be included in the DSF.

2.2 Definition of the term 'wetland'

Of all habitat types, wetlands are among the most difficult to define because they have soils (or sediments) and are thus not totally aquatic systems such as planktonic or pelagic environments. But they also have standing water, at least for some of the time, and are thus also not truly terrestrial. The dual nature of wetlands has led to their definition being varied, often confusing, and sometimes even contradictory (Mitsch and Gosselink 1993). Notwithstanding the problems with definition, it is widely acknowledged that wetlands commonly share four characteristics:

1. Water is present, either at the surface or within the root zone, for at least some of the time.
2. The water moves very slowly or is static (i.e. wetlands are lentic environments) unlike the case with flowing-water (or lotic) aquatic systems, such as rivers. Note that for coastal wetlands the speed of water flow may be modified by tidal influences.

[1] http://www.fao.org/docrep/008/a0266e/a0266e07.htm

[2] http://www.unep.org/NairobiConvention/docs/Coastal_zone_definition_and_geographic_coverage_of_the_ICZM_Protocol-Julien_Rochette.pdf

3. Waterlogging produces soils with anaerobic or anoxic characteristics that are quite unlike 'normal' terrestrial soils.
4. Vegetation is adapted to wet conditions and/or flooding, with plants not tolerant of flooding largely absent or restricted to ones with an annual life cycle to avoid the inundated phase.

Most of the current wetland definitions have been largely developed with an eye to inland wetland systems. In such systems there is no need to account for or include tidal or marine effects. Inundation and the formation of hydric soils often comes about because of the wetland's location on a floodplain, in a depressions subject to localised runoff, or as a consequence of groundwater expressing at the surface. But in coastal wetlands, a large majority (but not all, as discussed previously) of wetlands are influenced by the tides to various extents. In these cases, it is tidal inundation, not overbank riverine flow or groundwater discharge, that most often results in recurrent inundation, the formation on anaerobic sediments, and the development of a specialized flora.

Fortunately, the recent inventory of wetlands in Victoria (DEPI, 2013a), which applies the Victorian Wetland Classification Framework (consistent with ANAE classification), adopts four categories of wetland systems:

- Lacustrine – Non-tidal wetlands with less than 30% cover of emergent aquatic vegetation
- Palustrine – Non-tidal wetlands with more than 30% cover of emergent aquatic vegetation
- Semi-enclosed tidal wetlands
- Tidal wetlands in bays.

In the Victorian Wetland Classification Framework, tidal wetlands are further classified into two classes: marine or estuarine. Tidal wetlands classified as being 'marine' are those where freshwater inflows play a minor part in their ecology. Examples include Corner Inlet, Shallow Inlet, Anderson Inlet, Western Port Bay (including Quail Island, Rhyll Inlet and The Duck Splash) and wetlands within Port Phillip Bay (including Mud Islands). All other tidal wetlands are classified as estuarine (DEPI, 2013a).

2.3 What types of wetlands occur in the Victorian coastal zone?

Extensive and floristically and structurally diverse wetlands occur along much of the Victorian coastline (Barson and Calder 1981; Sinclair and Suter 2008; Boon 2012; Boon *et al*. 2015a; Frood *et al*. 2015). Of these, mangroves and coastal saltmarsh are perhaps the two most obvious and well-known types. Seagrass beds should also be considered as a type of coastal wetland, even if many reviews of the impacts of climate change on coastal wetlands neglect them from consideration. A suite of other wetland types also occur along the Victorian coast and although these are almost never mentioned in climate-change reviews, it is imperative that they be identified as bona fide wetland types. These other wetland types are considered in Section 2.3.4.

2.3.1 Mangroves

Mangroves are trees, shrubs or palms, usually taller than 0.5 m, that grow above mean sea level in the intertidal zone of marine coastal environments and along the margins of estuaries. Only one mangrove species, *Avicennia marina* var*. australasica*, is present in Victoria (Duke 2006) and the vegetation community it forms is classified as Ecological Vegetation Class (EVC) 140 Mangrove Shrubland. Mangroves extend in a discontinuous distribution from the Barwon River in the west to McLoughlins Beach in the east of the State (Barson and Calder 1981). They are particularly well developed around Western Port (including around French Island) and in the Corner Inlet-Nooramunga area of South Gippsland (Boon *et al*. 2015a). Mangroves are present also in Cunninghame Arm at Lakes Entrance, and are believed to be planted specimens that have become naturalized. The most southerly occurrence of mangroves in Australia (and the world) is in Victoria, near Millers Landing in Corner Inlet, at a latitude of 38^{o}45'S. Frost and/or low winter temperatures is believed to be the environmental factor that limits the distribution and vigour of mangroves in southern Victoria (Ashton 1971; Oliver 1982). Because they are at their geographic limit, mangroves in southern Victoria are physically small and have lower rates of primary productivity than those in more northerly parts of the continent.

2.3.2 Coastal saltmarsh

Coastal saltmarsh is more difficult to define than mangrove shrubland, and Boon *et al*. (2015a) proposed it be described as 'land that experiences recurrent low-energy inundation by seawater and which is vegetated by low-growing vascular plants (<1.5 m height), such as succulent chenopods and salt-tolerant monocots'. In contrast to many Northern Hemisphere saltmarshes (which are often dominated by grasses such as *Spartina* spp*.* and *Puccinellia* spp.), Victorian coastal saltmarsh is floristically and structurally highly diverse. The five structural types are as follows:

- succulent shrubs such as *Tecticornia* spp;
- large tussocky monocots (e.g. *Austrostipa stipoides* and *Gahnia filum*);
- low rhizomatous grasses (e.g. *Distichlis distichophylla* and *Sporobolus virginicus*);
- succulent herbs (e.g. *Sarcocornia* spp., *Hemichroa Pentandra* and *Disphyma clavellatum*); and
- prostrate shrubs (e.g. *Frankenia pauciflora* and *Wilsonia humilis*).

Coastal saltmarsh is found along many parts of the Victorian coast, but is best developed between Barwon Heads and Corner Inlet (Barson and Calder 1981; Boon *et al*. 2015a). Extensive areas occur along the western coast of Port Phillip Bay, northern parts of Western Port, in the Corner Inlet-Nooramunga complex, and behind the sand dunes that line the Ninety Mile Beach in Gippsland, especially in Lake Reeve. To the west of Barwon Heads, patches occur at Breamlea, the mouth of the Anglesea River and Aireys Inlet, at Port Fairy, and in the estuary of the Glenelg River. To the east of Corner Inlet, saltmarsh fringes the shoreline of the Gippsland Lakes and extends as far east as the mouth of the Snowy River, Wingan Inlet and Mallacoota. In response to the strong west-east gradient in rainfall along the coast, saltmarsh in the western parts of Victoria differs from that in the east (Barson and Calder 1981). A 'dry' type is present in central-western regions, where low summer rainfall and high temperatures lead to intensely hypersaline conditions in elevated sites; vegetation in these areas is often dominated by *Tecticornia pergranulata* and *Tecticornia halocnemoides*. The 'wet' type is found east of Western Port and is often dominated by samphires such as *Sarcocornia* spp. and *Tecticornia arbuscula*.

2.3.3 Seagrass beds

Seagrasses are often ignored in inventories of coastal wetlands, which tend to stress the more 'terrestrial' wetland types such as mangroves, saltmarshes and various types of coastal system dominated by woody or non-woody plant taxa. This might be because the water over seagrass beds is tidally modulated and is considered to be moving too quickly for them to be considered lentic systems. Seagrasses, however, are bona fide wetland types (at least under the Ramsar definition of wetlands) and in Victoria fall into two main groups: EVC 845 Sea-grass Meadow and EVC 854 Saline Aquatic Meadow. The former EVC is dominated by *Posidonia australis*, *Zostera* and/or *Heterozostera* spp, and can be variously intertidal or subtidal (Posidonia is obligately subtidal). The latter EVC is often − but not always − ephemeral and is typically dominated by *Ruppia megacarpa*, *Ruppia polycarpa*, *Lepilaena* spp. (e.g. *L. preissii*, *L. bilocularis*, *L. cylindrocarpa*).

2.3.4 Other types of coastal wetland

Although mangroves and saltmarsh are the coastal wetlands most readily recognised by lay people, both are commonly found nearby, or in mosaics with, a range of other estuarine wetlands that also experience a mixture of tidal and freshwater influences. These wetlands are frequently vegetated by dense stands of rhizomatous perennial monocots, including Sea Rush *Juncus kraussii* and Common Reed *Phragmites australis* in the seaward reaches, and *Bolboschoenus caldwellii* and *Schoenoplectus pungens* in areas further from the influence of sea water (Sinclair and Sutter 2008). Some of the other types of coastal wetland in Victoria include:

- Estuarine Wetland (EVC 010), dominated by *Juncus kraussii*, occasionally with *Phragmites australis* or species of *Cyperaceae*.
- Brackish Sedgeland (EVC 013), dominated by *Gahnia trifida* (sometimes *Gahnia filum*) and *Baumea juncea*.

- Swamp Scrub (EVC 053), dominated by *Melaleuca ericifolia*, *Leptospermum lanigerum*, with aquatic or semi-aquatic spp. such as *Isolepis inundata*, *Triglochin procera*, *Villarsia* spp. and *Sphagnum* spp.
- Brackish Wetland (EVC 656), dominated by *Bolboschoenus caldwelli* and/or *Schoenoplectus pungens* and aquatic semi-aquatic species tolerant of at least moderate salinity.
- Tall Marsh (EVC 821), typically vegetated with *Phragmites australis*, *Typha* spp. and *Schoenoplectus tabernaemontani*.
- Estuarine Reedbed (EVC 952), dominated by *Phragmites australis*, with associated species variously including *Samolus repens*, *Juncus kraussii*, *Triglochin striatum*, *Bolboschoenus caldwellii* and *Suaeda australis*.
- Estuarine Scrub (EVC 953) *Melaleuca ericifolia* (in eastern Victoria), with other *Melaleuca spp*. (e.g. *Melaleuca lanceolata*, *Melaleuca gibbosa*) or *Leptospermum lanigerum* in marginal sites in western Victoria. Ground-layer includes *Samolus repens*, *Triglochin striatum* and *Selliera radicans*, variously with *Sarcocornia quinqueflora*, *Gahnia filum*, *Poa poiformis*, *Juncus kraussii*, *Disphyma crassifolium* and *Distichlis distichophylla*.

Table 1 provides additional detail on some of the more common types of coastal wetland that occur in Victoria. They have been sorted by Ecological Vegetation Class, for reasons made clear in Section 2.5 of the report.

Table 1: Examples of coastal wetland types common in Victoria. ECV = Ecological Vegetation Class. Source: modified from Department of Sustainability and Environment (2012) and Boon (2012).

EVC	EVC Name	Characterisation	Indicator species
9	**Coastal Saltmarsh Aggregate**	Low, variously shrubby, herbaceous, sedgy or grassy vegetation of salinised coastal soils, in or adjacent to tidally influenced wetland. Coastal Saltmarsh can include a number of zones of varying structure and floristics, reflecting the regimen of tidal inundation and substrate character	Variously *Tecticornia arbuscula*, *Sarcocornia quinqueflora*, *Suaeda australis* and *Samolus repens*, often in association with *Frankenia pauciflora*, *Atriplex paludosa*, *Puccinellia stricta*, *Juncus kraussii*, *Hemichroa pentandra*, *Selliera radicans* and *Triglochin striata*. *Gahnia filum*, *Austrostipa stipoides*, *Sporobolus virginicus*, *Schoenus nitens*, *Wilsonia backhousei*, *Disphyma crassifolium* and *Distichlis distichophylla* can variously be locally prominent in more peripheral habitats.
10	**Estuarine Wetland**	Rushland/sedgeland vegetation, variously with component of small halophytic herbs, occurring in coastal areas where freshwater flows augment otherwise saline environments.	*Juncus kraussii*, occasionally with *Phragmites australis* or species of *Cyperaceae*.
13	**Brackish Sedgeland**	Sedgeland dominated by salt-tolerant sedges in association with a low grassy/herbaceous ground-layer with a halophytic component.	*Gahnia trifida* (sometimes *Gahnia filum*), *Baumea juncea*, with a mixture of species as for Brackish Herbland and species which are not obligate halophytes.
14	**Estuarine Flats Grassland**	Tussock grassland or grassy sedgeland beyond zone of normal tidal inundation but sometimes subject to seasonal water-logging or rarely brief intermittent inundation.	*Poa poiformis* with *Ficinia nodosa*, and including non-halophytic species such as *Senecio* spp., *Clematis microphylla* and *Acaena novae-zelandiae*.
53	**Swamp Scrub**	Dense (and potentially tall shrubby vegetation of swampy flats), dominated by Myrtaceous shrubs (to small trees), ground-layer often sparse, aquatic species conspicuous, sphagnum and/or	*Melaleuca ericifolia*, *Leptospermum lanigerum*, with aquatic / semi-aquatic spp. (e.g. *Isolepis inundata*, *Triglochin procera* s.l., *Villarsia* spp., *Sphagnum* spp.).

		water-logging tolerant ferns sometimes present.	
140	**Mangrove Shrubland**	Extremely species-poor shrubland vegetation of inter-tidal zone, dominated by mangroves.	Characteristically occurs as mono-specific stands of Avicennia marina. In some stands, species from adjacent Coastal Saltmarsh or Seagrass Meadow also present.
196	**Seasonally Inundated Subsaline Herbland**	Very species-poor low herbland of seasonal saline wetland within relicts of former tidal lagoons, dominated by Wilsonia spp.	*Wilsonia humilis* sometimes with *W. backhousei* and/or *W. rotundifolia*.
538	**Brackish Herbland**	Low herbland dominated by species tolerant of mildly saline conditions and rare intermittent inundation.	*Lobelia irrigua*, *Sebaea* spp., *Ranunculus* spp., *Apium annuum*, *Lachnagrostis* spp., *Isolepis cernua*, *Schoenus nitens*, *Wilsonia rotundifolia*; variously *Selliera radicans*, *Distichlis distichophylla* and/or *Samolus repens*.
656	**Brackish Wetland**	Collective label for the various zones of sedgy-herbaceous vegetation associated with sub-saline wetlands. Components variously include wetter versions of Brackish Sedgeland, Brackish Herbland and Saline Aquatic Meadow.	*Bolboschoenus caldwellii* and/or *Schoenoplectus pungens* and aquatic semi-aquatic species tolerant of at least moderate salinity.
821	**Tall Marsh**	Wetland dominated by tall emergent reeds, rushes or sedges, typically in dense, species-poor swards.	Typically *Phragmites australis*, *Typha* spp., *Schoenoplectus tabernaemontani*. Associated species are quite variable and can include *Calystegia sepium* and *Urtica incisa* and a range of aquatics.
842	**Saline Aquatic Meadow**	Submerged ephemeral or perennial herbland of slender monocots, occurring in brackish to saline water bodies subject or not to dry periods. The vegetation is characteristically extremely species-poor, consisting of one or more species of Lepilaena and/or Ruppia.	Variously *Ruppia megacarpa*, *Ruppia polycarpa*, *Lepilaena* spp. (e.g. *L. preissii, L. bilocularis, L. cylindrocarpa*).
845	**Sea-grass Meadow**	Sward-forming aquatic herbland of sheltered marine shallows, inter-tidal flats and lower estuarine habitats.	Dominated by *Zostera* and / or *Heterozostera* spp. (or localised variant also including *Lepilaena marina* and *Ruppia tuberosa*).
934	**Brackish Grassland**	Grassland on sub-saline heavy soils, including dominants of Plains Grassland (and a portion of associated herbaceous species) in association with herbaceous species indicative of saline soils.	*Poa labillardierei* / *Themeda triandra*, *Austrodanthonia* spp., *Distichlis distichophylla*, *Calocephalus lacteus*, *Selliera radicans*, *Sebaea* spp., *Wilsonia rotundifolia*, *Lobelia irrigua*; *Poa poiformis* in some coastal sites.
947	**Brackish Lignum Swamp**	Wetland dominated by Muehlenbeckia florulenta with a component or patches of salt-tolerant herbs (at least at low to moderate levels of salinity) and usually also with some species common to freshwater habitats. Can be very species-poor.	*Muehlenbeckia florulenta*, variously with *Samolus repens*, *Isolepis cernua*, *Triglochin striata*, *Chenopodium glaucum*, *Myriophyllum verrucosum*, *Selliera radicans*, *Mimulus repens*, *Distichlis distichophylla*, *Lobelia irrigua*, *Wilsonia rotundifolia*, *Lachnagrostis* spp. and/or *Gahnia filum*.

952	**Estuarine Reedbed**	Vegetation dominated by tall reeds (usually 2-3 m or more in height), in association with a sparse ground-layer of salt tolerant herbs. Distinguished from Estuarine Wetland by the vigour and total dominance of reeds, and from Tall Marsh by the presence of halophytes.	*Phragmites australis*, with associated species variously including *Samolus repens*, *Juncus kraussii*, *Triglochin striatum*, *Bolboschoenus caldwellii* and *Suaeda australis*.
953	**Estuarine Scrub**	Shrubland to scrub of Myrtaceous shrub species of sub-saline habitat, occurring in association with ground-layer including halophytic herbs.	*Melaleuca ericifolia* (in eastern Victoria), with other *Melaleuca* spp. (e.g. *Melaleuca lanceolata*, *Melaleuca gibbosa*) or *Leptospermum lanigerum* in marginal sites in western Victoria. Gound-layer includes *Samolus repens*, *Triglochin striata* and *Selliera radicans*, variously with *Sarcocornia quinqueflora*, *Gahnia filum*, *Poa poiformis*, *Juncus kraussii*, *Disphyma crassifolium*, *Distichlis distichophylla*.

2.3.5 Wetland zonation with elevation and tidal inundation

Because the coastal wetland vegetation is extensive, diverse and often subject to regular tidal inundation, in many locations it is sorted into clear zones with different plant communities according to elevation and distance from the sea. Areas that are subject to the most frequent tidal inundation are either mud- and sand-flats devoid of vascular plants (but still vegetated with microscopic algae) or vegetated with seagrasses. Slightly more elevated areas subject to regular (daily) tidal inundation support mangroves; higher areas subject to less-frequent inundation, coastal saltmarsh. The highest areas, furthest from the shoreline and inundated only at exceptionally high tides, often support paperbark (*Melaleuca* spp.) communities. Fully terrestrial vegetation lies behind these coastal wetlands, as shown in Figure 3, an idealized model of how the peripheral vegetation is zoned according to elevation, distance from the sea, and frequency/duration of tidal inundation in Western Port.

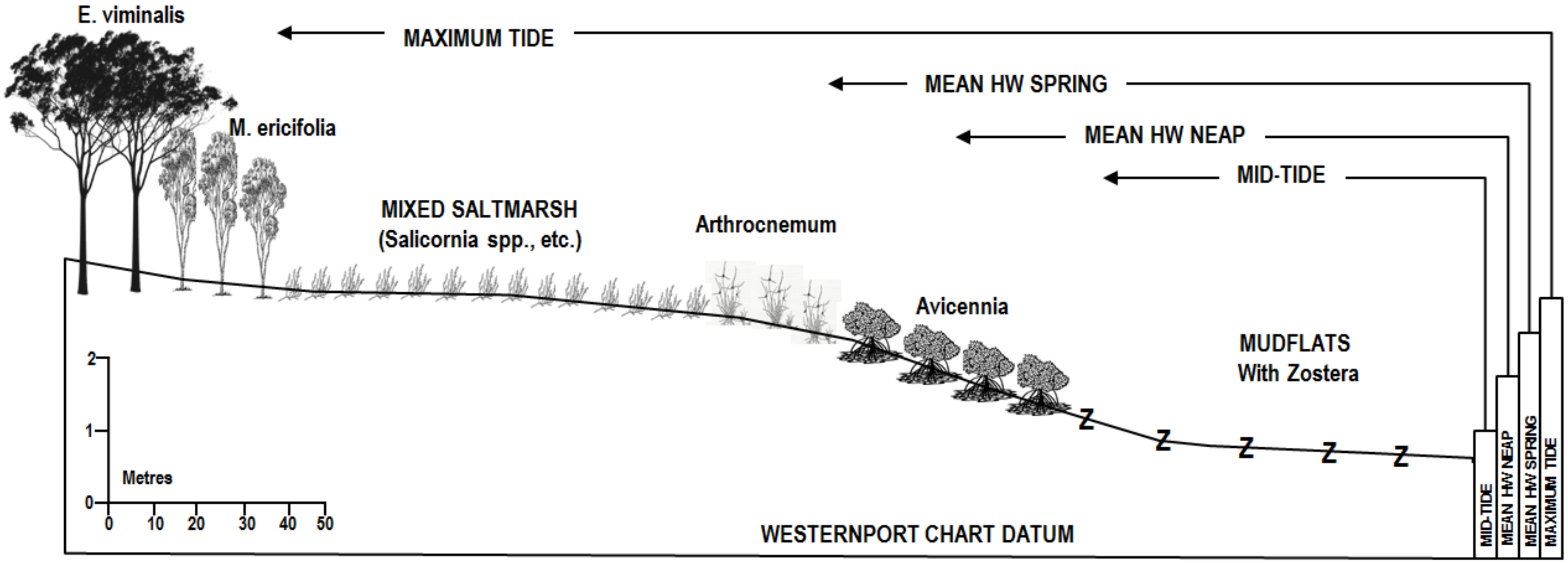


Figure 3: Model of the zonation of vegetation that fringes Western Port. Note that the genus *Arthrocnemum* is now known as *Tecticornia* (and formerly *Sclerostegia*). Source: Bird & Barson (1975, Figure 3).

2.4 Coastal wetlands

For the purposes of this project, coastal wetlands refer to any wetland that occurs within the 0−10 m AHD elevational zone around the coastline, with the addition of seagrass meadows. It is assumed that they all experience a marine influence to some extent or other, although not all are estuarine and even fewer are tidal.

The diversity of coastal wetlands within this definition means that they have to be categorised into a manageable number of wetland types in a relatively small number of landscape positions. This is simply a matter of pragmatism.

Although currently there is no single comprehensive typology for Victorian coastal wetlands and estuaries, a number of broad wetland groups can be identified on the basis of definitions provided in the Statewide wetland inventory (DEPI, 2013a). Note that this typology differs from others developed at the national or regional scale (e.g. Semeniuk and Semeniuk 1997; Roy *et al*. 2001). It is different too from the marine habitat classification system developed by Parks Victoria, which grouped marine habitats into two broad groups (intertidal and subtidal) and then further divided each into a very large number of smaller classes on the basis of substratum type, lithology and characteristic biota (Ball *et al*. 2006). The typology devised by Roy *et al*. (2001) is shown in Table 2 and is an all-encompassing scheme that describes all the aquatic environments (not just wetlands) that occur along the Australian coast. This classification distinguishes among 13 different types of coastal water bodies, divided into five broad groups. One group, ocean embayments, is completely marine. They are not estuaries, although they may include parts that are estuarine. One group includes bodies of water that are always fresh, for example, perched dune lakes. They are also not estuaries, but are still marine as they are subject to ocean influence. The other three groups are all estuarine, and they are sorted according to two characteristics: i) whether tides or waves dominate the movement of water and particles; and ii) whether they are always open or only intermittently open to the ocean. This typology has found widespread use over the past decade, partly because it offers national coverage and partly because it reflects the broad geomorphological and hydrological processes that govern the structure and function of coastal aquatic systems. Note that the Roy *et al*. (2001) typology does not explicitly include biota as a means of classification; different biotic or habitat types are secondary within this classification. The groups in Roy *et al*. (2001) overlap to some extent with the coastal typology outlined in the OzCoasts website[3], which differentiates among six broad types of coastal environment on the basis chiefly of geomorphological and hydrological features:

- Marine embayments and drowned river valleys
- Wave-dominated estuaries
- Tide-dominated estuaries
- Wave-dominated deltas
- Coastal lagoons and strandplains
- Tidal creeks

[3] http://www.ozcoasts.gov.au/conceptual_mods/geomorphic/emb/emb.jsp

Table 2: Classification of coastal water bodies in eastern Australia according to Roy *et al*. (2001).

Group	Type	Mature Form
I. Bays	1. Ocean embayments	Wave- or tide-dominated estuaries
II. Tide-dominated estuaries	2. Funnel-shaped macrotidal estuaries 3. Drowned river valleys 4. Tidal basins	Tidal estuaries
III. Wave-dominated estuaries	5. Barrier estuaries 6. Barrier lagoons 7. Interbarrier estuaries	Riverine estuaries
IV. Intermittent estuaries	8. Saline coastal lagoons 9. Small coastal creeks 10. Evaporative lagoons	Saline creeks
V. Freshwater bodies	11. Brackish barrier lakes 12. Perched dune lakes 13. Backswamps	Terrestrial swamps

The schema developed by Roy *et al*. (2001) also overlaps to some degree also with the typology used in DEPI (2013a). The choice then becomes which of the two competing schemes − Roy *et al*. (2001) or DELWP (2013a) − is better suited to this project. Although the Roy *et al*. (2001) scheme is more comprehensive and has an intrinsic geomorphological basis well suited to classifying coastal environments, the DEPI (2013a) scheme has the advantage of already having State endorsement and is specific to at least some coastal wetland types.

For the purposes of this project we have adopted a typology based on the Statewide typology used in DEPI (2013a), and also includes non-tidal coastal wetlands that may have a maritime influence (e.g. coastal floodplains, wetlands in coastal dune system/ swales) to yield a small, manageable group of broad wetland types (Figure 4).

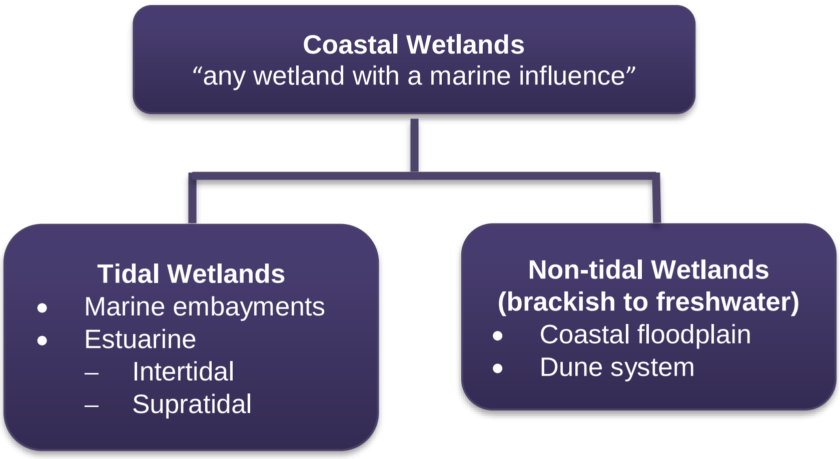


Figure 4: Coastal wetland categories adopted for this project.

The following sections provide further details on each of the broad coastal categories that arise from this typology.

2.4.1 Marine Embayments

Marine embayments are one of five major types of coastal geomorphological features identified in the typology of Roy *et al*. (2001). They are also a discrete unit in the DEPI (2013a) typology. Coastal embayments are very common in Victoria, and some of the State's largest coastal waterbodies fall into this category (e.g. Port Phillip Bay, Western Port). They are considered the evolutionary precursors of modern wave-and tide-dominated estuaries and deltas (Roy *et al*. 2001).

General Features[4]:

- Overwhelmingly oceanic, with the result that aquatic habitats are typically marine with extensive sub-tidal environments.
- Freshwater inflows from the surrounding catchment play a minor part in their hydrology, meaning that estuarine areas are spatially limited to the zones near the discharging rivers.
- Experience large volumes of marine inflows and outflows in sequence with the tides due to their generally wide, unconstricted entrance.
- High wave/tide energy at the wide entrance, depending on local conditions (e.g. embayments on tide-dominated coastlines will experience a higher tidal energy, whereas embayments on wave-dominated coastlines will experience higher wave energy). In Victoria, most embayments occur on wave-dominated coastlines because of the coast's relatively small tidal range (compared with, say, northern Australia).
- Further headward, total hydraulic energy is reduced, but significant wave/tide energy is able to penetrate the entire embayment.
- Fine and coarse sediments enter the embayments from the catchment. The amount and type of sediment input varies regionally, depending on catchment and climatic conditions, and the volume of freshwater input.
- Includes large areas of subtidal environments and, along the fringes, intertidal environments. Habitats include intertidal flats, rocky shores and reefs, coastal saltmarsh, mangroves, saltflats, seagrass and bare (sandy or muddy) subtidal areas, and sandy beaches. Swamp areas and freshwater wetlands tend to occur behind prograding sandbars.

Examples in Victoria:

- Port Phillip Bay
- Western Port Bay
- Corner Inlet
- Shallow Inlet
- Anderson Inlet.

2.4.2 Estuarine – intertidal

The second broad group of coastal habitats is estuaries. As noted earlier, estuaries are areas of the coast where freshwater, almost always from the flow of rivers discharging into the sea, mix with and dilute oceanic water. Because of their coastal position, estuaries are very often − but not always − tidal. They are quite different from coastal embayments, although those parts of an embayment where a coastal river enters the

[4] http://www.ozcoasts.gov.au/conceptual_mods/geomorphic/emb/emb.jsp

sea can be considered an estuary. Those parts of the estuary in the intertidal range falls into the second group in the typology of Figure 4: Estuarine− intertidal wetlands.

The degree of tidal exposure varies with the periodic alternation between neap and spring tides, the latter having the greater difference in height between low and high tide. The highest tide experienced along the coast under 'normal' conditions is called the Highest Astronomical Tide[5]. This is the highest tide that can be predicted under any combination of astronomical conditions and with average meteorological conditions. Its opposite is Lowest Astronomic Tide. More common are spring tides, which occur when the Moon and the Sun are aligned on the same or on opposite side of the Earth, in other words when there is a Full Moon or a New Moon. This alternation of tides generates a zone ~1.5 m in height between the spring low tide and the spring high tide: the 'intertidal zone'.

Because they provide a diverse range of habitats, including high-energy sandy beaches and channel sands, sheltered deep muddy basins, shallow water habitats, mangroves, saltmarshes and intertidal flats, estuaries can contain 'true estuarine' or euryhaline plant and animal species, as well as transient visitors from full marine environments. Depending upon entrance conditions, saltmarshes and mangroves often occur around the edges, and the high-energy conditions of the inlet produce a sandy substratum and relatively clear shallow waters, which in turn can support beds of seagrasses. As shown in Figure 3, wetland communities are often zoned along this elevational gradient, with seagrasses in the lowest intertidal zone, mangroves slightly higher, and coastal saltmarsh at the limit of the high spring tide, sometimes slightly higher to the location of the Highest Astronomical Tide.

General features:

- Inundated twice daily with the tide, with inundation variously lasting hours between tide cycles, according to position in the landscape and local factors that influence tidal penetration (e.g. constricted entrances). The semi-diurnal tidal regime in south-eastern Australia means that most areas are exposed and are inundated twice a day, with the difference in tidal height typically varying ~ 1−2 m[6].
- The water in estuaries has a highly variable salinity regime, derived from the mix of saltwater tides coming in from the ocean and the freshwater from the river. Salinity regimes can fluctuate between salty and fresh.
- Includes a wide range of habitats, including seagrass beds, mangroves and coastal saltmarsh, other types of coastal brackish-water wetland and intertidal flats.

Examples in Victoria:

- Nooramunga complex
- Mouths of rivers discharging to coastal embayments: e.g. lower Yarra and Maribyrnong Rivers
- Lower Mitchell, Nicolson and Tambo Rivers and Snowy River in eastern Victoria; Lower Barwon and Glenelg Rivers in western Victoria; short coastal rivers in Otway Basin and South Gippsland: e.g. Powlett River.

2.4.3 Estuarine – supratidal

Lying at higher elevations than the intertidal zone of estuaries is the supratidal zone. In estuarine settings, mangroves are most commonly found in the intertidal zone between mean low tide and mean high tide. Slightly more elevated, but still subject to recurrent tidal inundation, lies coastal saltmarsh (Boon et al. in press). At even higher elevations is the zone that is inundated only by exceptionally high tides (e.g. the Highest Astronomical Tide) or by storm surges. This is often an area colonized by coastal saltmarsh and types of woody, moderately salt-tolerant vegetation, often dominated by paperbarks (*Melaleuca* spp.) or tea-

[5] http://www.bom.gov.au/oceanography/projects/ntc/NTC_glossary.pdf

[6] http://www.abs.gov.au/ausstats/abs@.nsf/94713ad445ff1425ca25682000192af2/47edb7b37eb8dd76ca256a09001647aa!OpenDocument

trees (*Leptospermum* spp.)(Boon *et al*. in press). These are also considered to be coastal wetlands (see Section 2.3 earlier)

General Features:

- Inundated rarely, only several times per year, with the highest tides. May also receive salt inputs from wave splash.
- Often densely vegetated with various types of swamp scrub (*Melaleuca*) or tea-tree scrub (*Leptospermum*), often with a halophytic understorey of saltmarsh taxa.

Examples:

- Fringing areas of coastal lagoons around the Gippsland Lakes
- Connewarre complex on lower Barwon River.

2.4.4 Coastal floodplains

Coastal rivers, by definition, discharge into the sea. Many of these rivers have a well-developed floodplain, which in turn supports a wide range of habitats (Boon *et al*. 2016). Wetlands are often located on these floodplains, and they experience mostly freshwater conditions but with the occasional intrusion of saline ocean water following exceptionally high tides, storm surges, or lake seiching.

General Features:

- Located on the floodplain of a coastal river.
- Relies on seasonal or intermittent flooding from a river as main source of water from the catchment, supplemented to various degrees with intrusions of marine water from the sea. Local runoff can contribute to the maintenance of freshwater sites between floods, allowing small ponds to fill after heavy rainfall.
- A wide range of vegetation, terrestrial and wetland, occurs on coastal floodplains (Boon *et al*. in press). Examples include coastal saltmarsh at lower elevations, swamp scrubs and other woody wetland types at slightly higher elevations, and at the terrestrial end of the spectrum, coastal woodlands dominated in Victoria by tree and shrub taxa such as *Banksia*, *Myoporum* and *Eucalyptus*. Brackish water and freshwater wetlands may occur on the floodplain as well, often dominated by taxa such as *Juncus kraussii*, *Phragmites australis*, *Bolboschoenus* spp. and *Cladium* spp.

Examples:

- Lower Snowy and Mitchell Rivers
- Merri River, Warrnambool
- Lower Glenelg River.

2.4.5 Dune systems

One of the coastal types identified in Roy *et al*. (2001) are coastal lagoons. Lagoon systems are very common along the coast of Victoria (Bird 1993), including systems such as the Gippsland Lakes and Lake Tyers in the east and myriad small intermittently open and closed lagoons in western Victoria along the Otway coast. Coastal lagoons and their associated strandplain coastal creeks are often small, shallow basins with very low (or negligible) freshwater inputs[7]. They are generally oriented parallel to the coast, and develop on prograding coastal sequences formed from beach ridges, dunes and barriers. The barrier that separates them from the ocean is a distinctive component of wave-dominated estuaries and are common along high-energy coastlines (e.g. along the Ninety Mile Beach in eastern Victoria). The barriers often consist of an

[7] http://www.ozcoasts.gov.au/conceptual_mods/geomorphic/coast_lagoon/cl.jsp

intertidal-to-supratidal beach-face with a berm opening to the lagoon and in the near hinterland a series of dunes interspersed by blow-outs. Wetlands of various size can develop in the swales of these dune systems, including backswamps and perched wetlands (Table 2).

General Features:

- Occur on coastal sand dunes or plains behind the present beach and foredune.
- Dependent on groundwater and runoff from local catchments.

Examples:

- Johnstone Creek lakes, Discovery Bay
- Belfast Lough, Port Fairy
- Ewing Morass, east Gippsland
- Lake Barracoota, Mallacoota.

2.5 Spatial distribution of coastal wetlands across Victoria

2.5.1 Which is the best spatial dataset to delimit the coastal zone?

Based on the definition of the term 'coastal' provided in Section 2.2 − the area of marine influence within 0 to 10 m AHD of the shoreline − the only readily available dataset to map the 0-10 m AHD boundary is the VicMap Digital Elevation Model (DEM) which maps 10 m and 20 m contours across Victoria. Although a finer resolution (0.5 m and 1 m contours) VicMap DEM used in the Victorian Coastal Inundation mapping (DEPI, 2010) is available, the contours are only available in 2 km x 2 km tiles. This makes it an unusable form for State-wide mapping without undertaking comprehensive spatial analysis, which is outside the scope of the project.

2.5.2 Which is the best spatial dataset to identify wetlands in the coastal zone?

The next step was to identify which of the available spatial datasets was most suitable for identifying wetlands within this 0−10 m AHD area defined as the coastal zone. Victoria has two main datasets that could provide a spatial distribution of the wetlands:

- Statewide wetland inventory (DEPI, 2013a)
- Native Vegetation - Modelled 2005 Ecological Vegetation Classes (with Bioregional Conservation Status) (DEPI, 2008).

The Statewide wetlands inventory (DEPI, 2013a) provides wetland mapping across Victoria and a classification of wetlands in accordance with Victoria's new aquatic system classification framework. The classification framework includes six classification attributes and a range of possible categories under each attribute (Table 3).

Table 3: Summary of the Victorian classification framework attributes and categories (DEPI, 2013a)

Classification attribute	Possible categories	Category definition
Wetland system	Lacustrine	Non-tidal wetland with less than 30% cover of emergent aquatic vegetation
	Palustrine	Non-tidal wetland with greater than 30% cover of emergent aquatic vegetation
	Estuarine	Semi-enclosed tidal wetlands
	Marine	Tidal wetlands in bays
Salinity	Fresh	Wetlands with salinity concentrations between 0 and 3,000 mg/L

regime	Saline – Hyposaline	Wetlands with salinity concentrations between 3,000 and 10,000 mg/L
	Saline – Mesosaline	Wetlands with salinity concentrations between 10,000 and 50,000 mg/L
	Saline – Hypersaline	Wetlands with salinity concentrations between 50,000 and 350,000 mg/L
Water regime	Intertidal	Inundated twice daily, with inundation lasting hours between tide cycles
	Supratidal	Inundated several times per year, with inundation lasting days to months
	Permanent	Inundated constantly, rarely drying completely
	Periodically inundated	Inundated annually to infrequently, holding water for 1 month to 1 year before drying
Water source	Groundwater	Wetlands coinciding with mapped groundwater-dependent ecosystems
	River	Wetlands that receive water from in-channel or overbank river flows
	Local surface runoff	Wetlands that receive water from local runoff
	Tidal	Wetlands which are inundated by regular or spring tides
	Artificial	Wetlands which depend on an artificial water source
Dominant vegetation	Forest/ woodland	Applicable for lacustrine or palustrine systems
	Shrub	Applicable for lacustrine or palustrine systems
	Sedge/ grass/ forb	Applicable for lacustrine or palustrine systems
	Fern	Applicable for lacustrine or palustrine systems
	Moss/ heath	Applicable for lacustrine or palustrine systems
	Mangrove	Applicable for marine or estuarine systems
	Coastal saltmarsh	Applicable for marine or estuarine systems
	Seagrass	Applicable for marine or estuarine systems
	No emergent vegetation	Applicable for all wetland systems
Wetland origin	Naturally occurring	Wetlands of natural origin which essentially retain their natural form
	Human-made	Purpose built wetlands

The modelled EVC mapping (NV2005_EVCBCS) developed for vegetation quality assessments in DELWP's Habitat Hectares program provides an alternative approach to the identification of wetlands in the coastal zone. An EVC is defined as one or a number of floristic communities that appear to be associated with a recognisable environmental niche, and which can be characterised by a number of their adaptive responses to ecological processes that operate at the landscape scale (DSE 2009, 2012). Wetland EVCs were developed for use in DELWP's Index of Wetland Condition, however these have not been mapped across the state and therefore cannot be applied in this project to identify wetlands in the coastal zone. The modelled EVC layer provides modelled EVC distribution which can be used to predict whether there is an EVC present that is associated with a wetland. The modelled EVC mapping therefore does not provide a representation of the actual occurrence of an EVC at a given location and as such groundtruthing is at a local scale is necessary for confirmation. Currently there are over 130 wetland EVCs (Department of Sustainability and Environment 2012). Table 1 showed an overview of some of the more common types of coastal wetland EVCs in Victoria.

The Statewide wetland inventory and modelled EVC mapping were compared to determine which was more suitable for this project. The main difference between the two datasets was that the Statewide wetland inventory mapped the maximum extent of inundation as the boundary of the wetland, whereas the modelled EVC mapping used the different botanical communities as the boundary. Appendix B provides details on the comparison.

The ability to distinguish among different botanical − and therefore, it is assumed ecological − communities and values is important in this project because different wetland types will response differently to various aspects of climate change. Because of this, it was decided that modelled EVC mapping provided the more pragmatic approach to spatially defining wetlands in this project. A major strength of the modelled EVC mapping dataset is that it also provides additional information that can be used to help define wetland structure and function which can then be linked to wetland value and sensitivity. There will be some site differences in the EVCs, but the DSF takes into consideration location specific differences. It is also recognises that the modelled EVC mapping is patchy and where more detailed data are available (i.e. Boon *et al*. 2015a) it was used.

Based on the definition of a coastal wetland applied in this project, a notable omission from both the modelled EVC mapping and the Statewide wetland inventory was estuaries and seagrass. Therefore the following spatial datasets that are currently available for mapping estuaries and seagrass were also used to map wetlands in the coastal zone:

- Victorian estuaries dataset (Deakin University 2008)
- Distribution of seagrass in Western Port in 1999 (DPI 1999).
- Port Phillip Bay seagrass 2000 in Port Phillip Bay classified with CBiCS (DELWP 2016)
- Anderson Inlet seagrass 1999 (DPI 1999)
- Corner Inlet seagrass 1998 (DPI 1998)
- Gippsland Lakes seagrass 1997 (DPI 1997)
- Mallacoota Inlet seagrass 1999 (DPI 1999)
- Shallow Inlet seagrass 1999 (DPI 1999)
- Sydenham Inlet seagrass 1999 (DPI 1999)
- Tamboon Inlet seagrass 1999 (DPI 1999)
- Wingan Inlet seagrass 1999 (DPI 1999)

2.5.3 Applying the EVC database to identify coastal wetlands

Once the datasets were selected to spatially delimit the coastal zone and then to identify wetlands within this zone, the next step was to develop the coastal wetland dataset for Victoria. This was done in the following way:

- Combine the Modelled 2005 EVC (NV2005_EVCBCS) dataset with the more detailed mapping of mangrove and coastal saltmarsh EVCs compiled as part of the Victorian Saltmarsh Study (Boon et al. (2011, 2015a). Where available, the more detailed or recent spatial data sets overrides the modelled EVC mapping.
- Extract a list of all the individual EVCs and EVCs groups within the 0-10 m AHD boundary.
- Identify those individual EVCs that should be considered to represent wetlands. This allocation was based on the list of wetland and estuary-dependent EVCs provided by DELWP, benchmarks for wetland ecological vegetation classes in Victoria (DEPI, 2013b), the likely salinity and inundation

tolerances of various EVCs collated by Frood (2012), and expert knowledge. It was checked by regional managers at the stakeholder workshop on Wetland identification, value and sensitivity (22 July 2015) and revised accordingly. A full list of EVCs in the coastal zone and their wetland classification is provided in Appendix C.

- Overlay the Statewide wetland inventory to identify any wetlands within the 0-10 m AHD boundary of Victoria that has not already been mapped as an EVC and combine with the shortlisted coastal wetland EVCs identified.
- Overlay the Victorian estuaries dataset (Deakin University, 2008) to identify any sections of estuaries that were not mapped as a coastal wetland in the previous steps. Combine with the shortlisted coastal wetland EVCs and coastal wetlands in the wetland inventory identified to produce one coastal wetland dataset for Victoria. This step was necessary because some estuaries were not associated with a wetland EVC. For example, the Glenelg River estuary, which based on EVC mapping alone was not identified as a coastal wetland. This step ensured that the entire estuarine reach of the Glenelg River was captured as a coastal wetland that would be potentially at risk from climate change.
- A separate dataset was developed for seagrass beds as the seagrass datasets overlap the EVC and estuary mapping in a number of cases and if combined in to one overall dataset the detail of the EVC and wetland mapping may be lost. All available seagrass datasets for Victoria were combined into one dataset.

It is important to stress that the spatial datasets used to identify coastal wetlands were the best available data at the time of undertaking this project. These datasets will undoubtedly be updated in the future and may provide better indications of the complex mosaic of coastal wetlands in Victoria.

2.5.4 Coastal wetland mapping

Figure 6 provides a map of coastal wetlands at a Statewide scale and Appendix D provides regional scale maps identifying coastal wetlands within each of the five coastal catchment management authorities in Victoria.

The coastal wetland dataset for Victoria will also be provided as an output of this project to provide more detail at a local scale and can also be interrogated to extract information on wetland and EVC type.

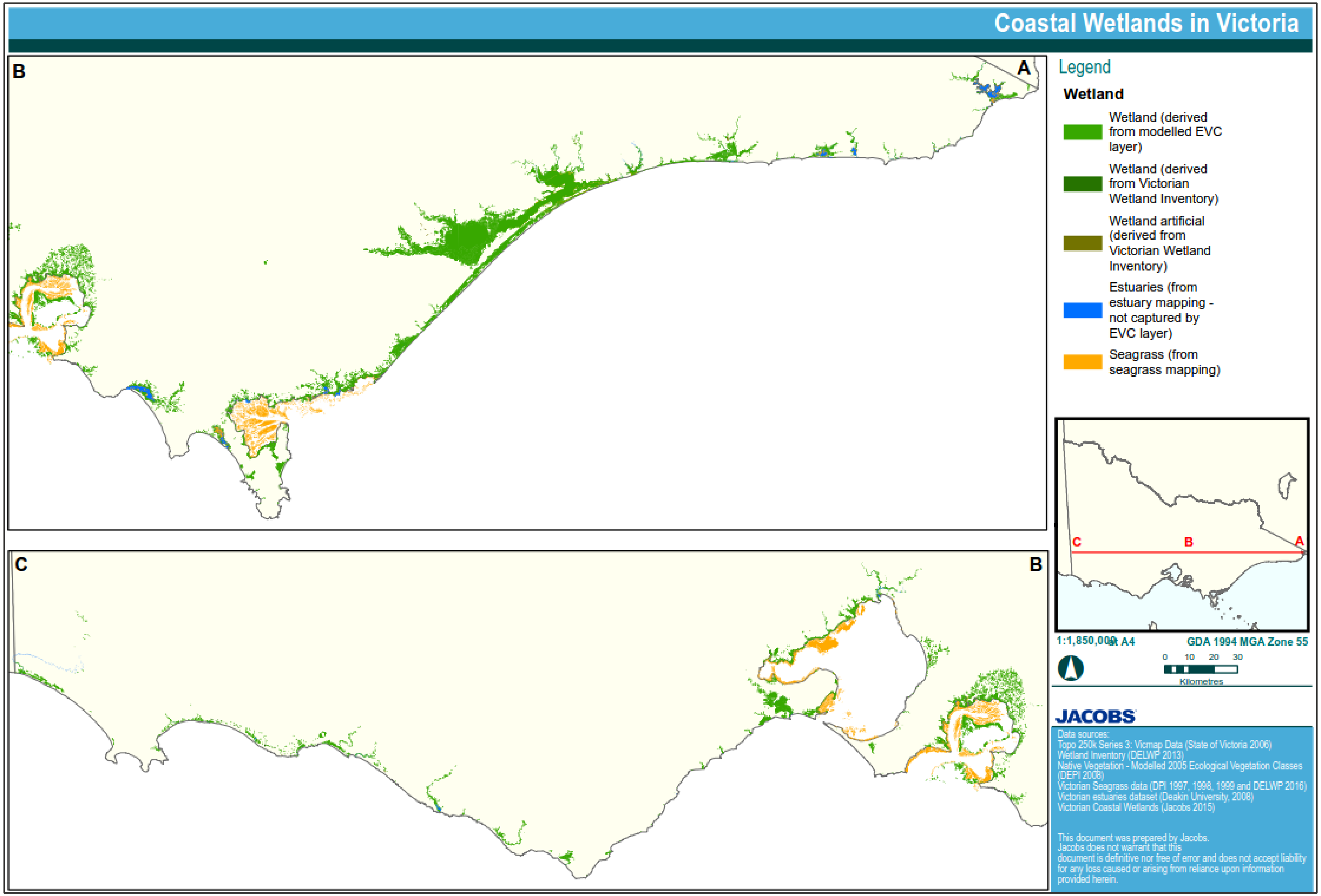


Figure 6: Spatial identification of coastal wetlands in Victoria (non-wetland EVCs in the 0-10mAHD coastal zone have been excluded in the mapping)

3. What is climate change in the coastal context?

3.1 Components of climate change

Coastal wetlands are especially vulnerable to the impacts of climate change because of their location. The most recent projections for south-eastern Australia by CSIRO-BOM (2015a, b) indicate that mean sea level will continue to rise and there will be more extreme sea level events such as storm surges. There is very high confidence in these projections. Rising sea levels is one of the most studied and best understood facets of global climate change. There is also very high confidence in projections that there will be more hot days and warm spells in south-eastern Australia. Fewer frosts are projected. As noted in Section 2.3.1, frost and/or low winter temperatures are believed to limit the distribution and vigour of mangroves in southern Victoria. The higher temperatures and relief from frost will likely see major changes in the productivity of mangrove communities along the Victorian coast. Some of these impacts are already observable in the coastal environment. The recent (post-1980) appearance of the mangrove *Avicennia marina* in the Gippsland Lakes, as described by Boon *et al*. (2015b, c) is a possible example.

Climate change also encompasses a wide range of other components (e.g. higher temperatures, decrease in frost, higher CO_2 concentrations and increased risks of fire), many of which are likely to have major impacts on coastal wetlands (Osland *et al*. 2016). The topic is too large and the interactions among various elements and the biota too complex to deal with unless the various components are divided into a smaller set of manageable units as set our below. Other approaches have been used in, for example, Hobday *et al*. (2006, 2011), Gilman *et al*. (2007, 2008), Adam (2008), Steffen *et al*. (2009 a, b), Gitay *et al*. (2011) and Finlayson *et al*. (2013).

For the purposes of our analysis it is useful to distinguish between the climate-related factors that directly influence the biota of wetlands, usually via physiological impacts, and those that exert indirect effects, often mediated through species interactions or from secondary changes to the environment.

Figure 7 shows a conceptual approach to handle the complexity of the topic. This approach has the advantage of differentiating between direct impacts and indirect impacts and the feedback that occurs between the physical environment and the biotic response to altered physiochemical conditions. It is important to note that uncertainty is associated with each step, and these inevitably introduce some vagueness in the diagnosis.

The approach commences with the recognition that a range of emission scenarios are possible, ranging from 'business as usual' to almost complete elimination of carbon emissions from human activities. This is a crucial consideration, as it makes explicit the fact that climate change impacts over the longer term will be controlled fundamentally by the choices we as a society make about greenhouse-gas emissions. This matter is taken up again later in this report, in Section 3.3.3. Emission scenarios feed into global climate models to yield climate projections at a global scale; global projections are then downscaled to generate regional climate scenarios. Both steps have large uncertainties associated with them.

Regional climate projections then feed into an analysis of ecological consequences for wetland structure, function and value via two main pathways:

- the direct effect of altered climate on wetland biota (mostly via physiological mechanisms)
- a suite of indirect effects arising from secondary, mostly physical, consequences of these two primary components.

The indirect effects are often associated with secondary changes to the physical environment, such as altered hydrology and changes to runoff. They can be associated also with complex ecological interactions among species (e.g. rates of herbivory, competition among species sharing a similar niche, or the availability of insect pollinators for flowering plants), effects on major ecological processes (e.g. rates of primary production and decomposition) and the complex patterns of feedback between climate, hydrology and vegetation.

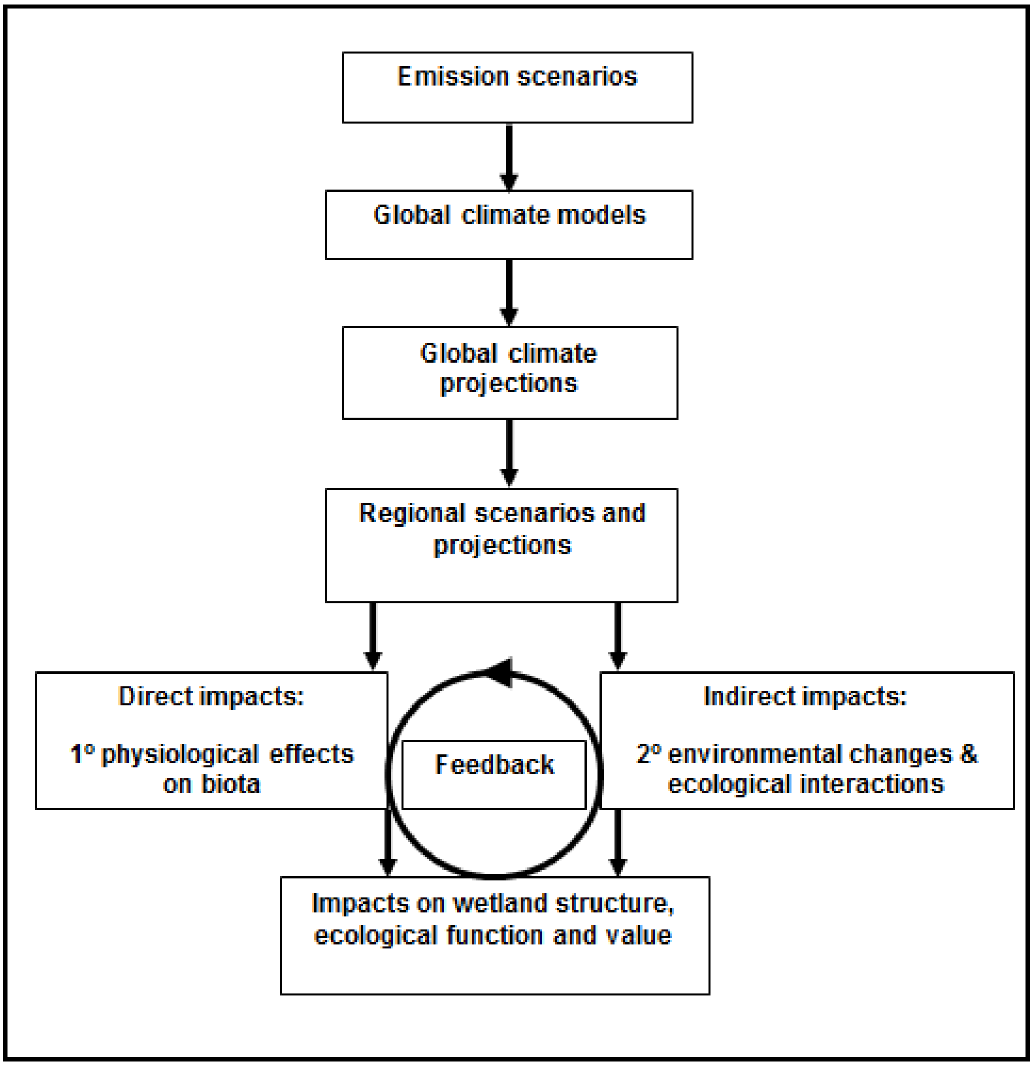


Figure 7: Conceptual approach to predicting the effect of different climate-change components on coastal wetlands. Source: modified from Boon *et al*. (2011)

The conceptual model shown in Figure 7 also explicitly separates direct impacts of climate change from indirect impacts. Direct (first degree) impacts are those that derive from primary impacts on the biota by a component of climate change, direct impacts of climate change are considered to have two fundamental, or primary, components:

- increase in atmospheric greenhouse gases (e.g. carbon dioxide and methane)
- increase in air and water temperatures that occurs as result of this increase in trapping of infra-red gases by greenhouse-gas active gasses.

These two primary components influence wetland biota directly, via a suite of physiological and phenological effects (Lovelock *et al*. no date). The trends in both variables are reasonably well understood (CSIRO-BOM 2015a, b), and the ecological consequences for coastal wetlands of changes in these two components is discussed in detail later.

Indirect (second degree) climate change components occur as a secondary response to these two primary factors. Indirect components include:

- increases in eustatic sea level as a consequence of i) thermal expansion of the oceans and ii) melting of terrestrial ice masses
- changes to regional patterns of rainfall and evaporation

- altered rates of freshwater runoff and river discharge
- increased incidence of extreme events (e.g. storm surges, flood and drought, heat waves etc)
- acidification of marine waters.

These are considered indirect impacts because, even though they are critical, they occur as a consequence of the two primary processes that drive climate change: higher air and water temperatures forced by increased concentrations of CO_2 (and other greenhouse-active gases) in the atmosphere. The increase in sea levels, for example, is not a direct phenomenon of climate change but is a consequence driven by higher air and water temperatures. Similarly, changes to regional patterns of rainfall are driven by a warmer atmosphere that can hold more water vapour.

The two suites of direct and indirect factors then combine to generate a huge array of possible impacts on wetland ecological structure and function and wetland values. Examples include:

- increased coastal erosion and shoreline recession, resulting in the physical loss of wetland habitat
- changes to the inundation regimes, resulting in altered wetting and drying cycles
- changes in salinity regimes, also influencing plant and animal dynamics
- increased incidence of wild fires, changing patterns of sediment and nutrient loads
- increased incidence of peat fires, leading to physical loss of coastal wetland habitat
- altered river discharge, leading to altered patterns of coastal deposition and nutrient cycling
- a wide suite of ecological interactions, including changes to the competitive interactions among species, altered rates of herbivory and changes to species composition including invasions by exotic taxa.

There is much less certainty as to the ecological outcomes of these changes and interactions, especially for coastal wetlands (Hobday and Lough 2011; Lovelock *et al*. no date).

The impact of sea-level rise is one of the better-understood secondary factors, with rates well documented for the Australian coastline (Lough and Hobday 2011; Lovelock *et al* no date) but it is critical to note that it is not the only element of climate change that will affect coastal wetlands (Osland *et al*. 2016). There is, however, a long tradition of considering changes in sea levels and increase in extreme events (storm surges, the incidence and severity or droughts and floods, and heat waves) as a primary component of climate change (e.g., Burroughs 2005, 2007).

Climate change includes changes to a wide spectrum of climate variables, including temperature (of the air and the water), rainfall, extreme events, wind strength and direction, solar irradiation and evaporation. In turn, these have a myriad of secondary or indirect consequences, including changes to sea levels, river discharge and events in the catchment (e.g. wild fire). Together, all these factors interact, often in ways that are poorly understood, to alter the environment in which coastal wetlands form and evolve. Moreover, the consequences of climate change on coastal wetlands is influenced also by a wide suite of social and political factors: extraction of surface and ground waters for irrigation, industrial and domestic uses, leading to changes in river discharge; changes to human demographics, including the 'sea change' phenomenon; the willingness of coastal communities to pay through altered infrastructure (e.g. removal of sea walls) to alleviate the impacts of sea-level rise on coastal ecosystems.

The question then becomes one of how to identify which of these huge number of interacting factors are the most critical for this project.

3.2 Critical climate-change components for coastal wetlands

A list of the general climate change components relevant in Australia is provided in Appendix E. DELWP and wetland managers were consulted during the project to identify the climate change components to be used in this project, based on their relevance to the coastal environment and the ability of their consequences to be managed. The most relevant components are listed in Table 4 and are discussed in further detail in the following sections.

Table 4: Critical climate change components for consideration in this project

Climate change component	Climate change driver	Implications for coastal wetlands
Sea level	• Increased eustatic sea level • Increased (incidence and severity) storm surge intrusions	• Altered inundation patterns • Altered salinity regimes, both from chronic (press) and pulse (events) • Increased coastal erosion and shoreline recession • Salt water intrusion into groundwater • Altered underwater light regimes (seagrass beds only)
Carbon dioxide concentration	• Increased atmospheric CO_2 concentration • Acidification of the water column	• Altered competitive relationships between C3 and C4 plants • Carbonate dissolution and adverse impact on marine invertebrates • Possible effects of carbon uptake by submerged plants (seagrass beds only)
Rainfall	• Changes (mostly lower) in annual average rainfall • Changes in seasonal rainfall distributions • More variable rainfall, including an increase in the frequency or severity of extreme events (e.g. storms)	• Changes to river discharge (average and extremes) • Altered inundation patterns • Altered salinity regimes, both from chronic (press) and pulse (events) • Altered groundwater regimes (changes in recharge patterns) • Increased risk of wildfire, with possible direct impacts via coastal wetlands catching fire and indirect impacts via altered sediment and nutrient discharge to coastal systems
Temperature	• Higher air temperatures • Higher water temperatures • Increased frequency or severity of extreme events (e.g. heat waves)	• Wide range of phenological impacts • Increased (?) primary productivity and decomposition processes • Altered salinity regimes, both from chronic (press) and pulse (events)

Table 4 shows that four climate-change variables were judged as critical during the stakeholder consultation. Three of these − sea level rise and associated storm-surge activity; carbon dioxide concentrations; and higher air and water temperatures − fall within the primary or direct factors outlined in Figure 7. One − altered rainfall patterns − is a secondary component of climate change. The following text explains why each of these four factors or components was assessed as being of high priority.

3.2.1 Changes in eustatic sea level and increased storm-surge activity

Eustatic sea level refers to the global average sea level and must be contrasted to regional or local changes in sea level, which occur as a consequence of changes in the level of land, for example due to subsidence. The most obvious impact of rises in eustatic sea levels is that coastal wetlands will be inundated more frequently and more deeply with sea water. This will affect inundation regimes (i.e. wetting and drying cycles) and salinity regimes in the wetlands.

The simplest expectation is that saltmarshes would be replaced by mangroves, and mangroves by seagrasses. In more elevated positions along the coast, the frequency of inundation from storm surges will likely increase and this would be expected to have profound effects on the water and salinity regimes in fringing wetlands. Saltmarsh may invade into paperbark or tea-tree woodlands. In turn, *Juncuss kraussii* and other brackish-water taxa may also migrate into the hinterland, into currently terrestrial plant communities dominated by, for example, Manna Gum *Eucalyptus viminalis*. Steep hills or dunes discourage the formation of extensive wetlands and, in a number of places along the Victoria coast (e.g. around Phillip Island and along the Otway coast), peripheral vegetation abuts steep terrain and thus has nowhere to retreat should sea levels rise. Moreover, the intensity of development on coastal plains, often for housing but also for industrial facilities such as ports, has been such that there is little or no room left around much of the coast for a landward retreat of peripheral vegetation as sea levels rise.

There is surprisingly little known about the tolerance of coastal wetland plants to altered inundation or salinity regimes (Boon 2012). The best studied species is the mangrove, *Avicennia marina*. In broad terms, the anatomical and physiological adaptations that allow this species to grow in saline environments are well understood, but in an exhaustive review of temperate mangroves, Morrisey *et al*. (2010) could cite only one publication on the salinity requirements of *Avicennia marina* in southern Australia, and that study concerned seedlings not adult plants. The quantitative information base on hydrological and salinity regimes for plants in saltmarshes and other types of non-mangrove coastal wetlands is even less well understood. Unlike the voluminous information available on the way plants in inland wetlands respond to different water regimes and to salinity, there is very little available on these topics for plants in coastal or estuarine environments, especially in temperate Australia. This presents a serious limitation to our predictive ability. It is known, in general, that mangrove, saltmarsh and estuarine-wetland vegetation is particularly sensitive to subtle changes to salinity and hydrological regimes (e.g. see Burley *et al*. 2012).

The likely response of seagrass beds to higher sea levels is also not well understood. Impacts can be manifest via a number of pathways, as higher sea levels will alter inundation patterns of intertidal systems and for subtidal systems will also alter the underwater light regime. There is a paucity of research on the water depth/light/growth rate response for Victorian seagrass systems, with the only available studies being those of Doug Bulthius in 1983, and they were limited to *Heterozostera tasmanica*. The two other genera of seagrasses that occur in Victoria − *Posidonia* and *Zostera* − are completely understudied, as are the taxa found in EVC 854 Saline Aquatic Meadow. The most detailed assessment to date is Morris (2013), who predicted impacts arising from changes to sea levels, ocean currents, salinity and temperature, wave action, and rainfall and run off. Of these, salinity was concluded to be the least important and changes to sea levels, ocean current, temperature, rainfall and runoff among the most critical.

Closely linked to rising sea levels and an increase in the incidence and severity of storm surges is the likelihood of more severe coastal erosion and shoreline recession. Rising sea levels may inundate the more low-lying coastal wetlands, and as described above they will respond by moving to higher land. But it is also possible that rising sea levels, compounded by extreme events such as recurrent storm surges, will see much faster rates of shoreline recession and the complete destruction of former coastal wetland habitat. A simple application of Bruun's Rule (Walsh 2004) suggests that, under Rahmstorf's *et al*. (2007) estimates of global sea-level rise, the Victorian coast would retreat by 50−140 m by the end of the century. Shorelines developed on unconsolidated sediment (sand, silt, and clay), organic deposits or other poorly consolidated material such as weakly indurated sandstone or mudstone would be most sensitive, and it is these that often support coastal wetlands. Rapid rates of shoreline erosion have already been reported for parts of the Gippsland Lakes, for example, by Sjerp *et al*. (2002).

One aspect often not considered is the effect that increasing sea level or the increased frequency and severity of storm surges will have on coastal geomorphology. Impacts are almost always considered in terms of impacts on plant communities, but the fundamental geomorphological and hydrological conditions of coastal systems, especially estuaries will be affected as well. Higher sea levels and more frequent storm surges may convert an intermittently open and closed lagoon system to one that is constantly open to the ocean. In the case of barrier systems, the sand barriers may be washed away and the formerly estuarine system shift into a fully marine system. Such conversions can be accommodated within the typology outlined by Roy *et al*. (2001) and summarised in Table 2.

3.2.2 Increased carbon dioxide

Changes in ambient CO_2 concentration will directly affect the growth of plants via fundamental effects on photosynthesis and water use. This effect will occur because different species of plant fix atmospheric CO_2 in different biochemical pathways, each of which has a competitive advantage in different environments. How different plant taxa might respond to higher concentrations of atmospheric CO_2 is reviewed in Section 4.1.2. An increase in the concentration of atmospheric carbon dioxide is also responsible for ocean acidification, as the extra CO_2 alters the balance between carbonate and bicarbonate in the ocean. This will have major impacts on marine invertebrates that lay down carbonate shells, such as coral reefs, through its impacts on aragonite chemistry (Steffan *et al*. 2009 a, b; Hobday and Lough 2011).

3.2.3 Increased temperature

An increase in ambient air or water temperatures will have wide-ranging effects on individual organisms and on ecosystem structure and function (Bonan 2002). Expected effects include phenological impacts (the timing of onset of different phases of an organism's development e.g. flowering, seed germination and establishment of seedlings), changes to the allocation of resources to above- and below-ground components (e.g. leaves and shoots versus roots and rhizomes, with impacts on physical stability and sensitivity to herbivory), changes to the allocation of resources to reproductive versus maintenance activities (e.g. investment in seeds and the success of sexual recruitment; shifts to clonal spread), effects on life history and longevity (e.g. shortened life spans due to heat stress or drought), and effects on competitive and mutualist interactions among different species (e.g. on pollination of plants by animal vectors).

As noted earlier, low winter air temperatures and/or the episodic occurrence of frosts have been proposed as the primary factors that control the growth and distribution of *Avicennia marina* in Victoria. Relieved of their current limitation by cold and/or frost, mangroves could expand their distribution, and possibly also their productivity, across southern Victoria, including in Western Port. There is some palaeobotanical evidence for a similar shift having taken place with *Avicennia marina* in New Zealand, where mangrove pollen has been preserved in early Holocene sediments ~150 km to the south of the present-day limit of the species and coinciding with a period when the climate was warmer than today (Morrissey *et al*. 2010). Other than this, however, little is known of the impacts of higher temperatures on coastal wetlands (Lovelock *et al*. no date).

Morris (2013) concluded that seagrass beds were highly vulnerable to higher temperatures in 10 of the 12 seagrass habitat types occurring in Victoria. The Great Barrier Reef Marine Park Authority similarly concluded that seagrass beds may be greatly affected by climate change: ‘While evidence suggests macroalgae may thrive in the changed conditions, seagrass may not fare so well’[8]. . Seagrasses may be adversely affected by climate change, and in particular the interaction between deeper inundation and higher water temperatures, because:

> ‘Seagrass photosynthesis rates are determined in part by water temperature. Increases in temperature can decrease the efficiency of photosynthesis; however the extent of this impact may be dependent on the species' reliance on light. For example, a species of seagrass that requires less light to grow will be less vulnerable to increased water temperature. The reverse is also true. Temperature also plays a role in seagrass flowering (and thus reproductive) patterns. Available information for this topic is limited; though it is expected temperature changes will have significant effects on the reproduction of most seagrass species.’

3.2.4 Changes in rainfall

Although the greatest and most obvious impacts of climate change on coastal wetlands in Victorian coast is likely to be caused by rises in mean and extreme sea levels, a suite of subtle – but still important − effects can be expected to arise as a consequence of altered patterns of rainfall and or freshwater run-off. The corresponding changes in river runoff will influence inundation and salinity regimes in coastal wetlands. The effects could be experienced either as decreased long-term local run-off into peripheral vegetation (e.g. from the immediate hinterland) or as altered base flows and patterns of over-bank flooding from rivers and streams during extreme events. In Western Australia, Hobday *et al*. (2006) noted the sensitivity of mangrove ecosystems to even slight changes to hydrological regimes, induced by either shifts in tidal inundation or fluxes of freshwater from the hinterland and nearby rivers. More recently, Eslami-Andargoli *et al.* (2010) have reported on the effects of drought on the expansion and contraction of mangroves in south-eastern Queensland. Other than these investigations, few studies have been undertaken on these topics,

[8] http://www.gbrmpa.gov.au/managing-the-reef/threats-to-the-reef/climate-change/what-does-this-mean-for-species/marine-plants

notwithstanding the high likelihood that changes to rainfall will have major impacts on the structure and function of coastal wetlands.

A secondary consequence of altered patterns of rainfall is altered groundwater regimes which can impact on the delivery of groundwater to coastal wetlands. This could result from changes to groundwater levels in the catchment arising from altered rates of extraction (e.g. to meet periodic shortages of potable water, as has occurred already in the Geelong area and the Barwon catchment) or from a lower rate of groundwater recharge following a depression in long-term rainfall. Groundwater inputs may be important to coastal wetlands because they provide freshwater to support the growth of largely salt-intolerant plants in saline environments. *Halophytic* and *glycophytic* species, for example, are often intermixed to form complex patterns and mosaics that reflect the interplay of site elevation, saline and fresh-water inundation, and groundwater flows. These transitional mosaics are often characterised by dense stands of perennial monocots, including *Juncus kraussii* and *Phragmites australis* in the seaward reaches, and *Bolboschoenus caldwellii* and *Schoenoplectus pungens* in areas further from the influence of seawater (Sinclair and Sutter 2008). A change to groundwater regime in the coastal zone also has the potential to result in the intrusion of sea water into the groundwater aquifer. The outcomes of this impact are hard to quantify, see Section 4.1.4 for a conceptualisation of the cumulative impact of a change in water regime on groundwater levels and sea water intrusion.

Changes to rainfall patterns (in terms of annual totals and seasonality) will also affect a wide range of catchment-scale processes. The interaction with higher air temperatures demonstrates the way different elements of climate change interact synergistically. Less rainfall and warmer summers will generate a higher fire risk, and this may be manifest as fires occurring within wetlands and as an increased fire risk for the catchment, with flow-on impacts on sediment and nutrient discharge to coastal systems. Contrary to popular views, coastal wetlands can burn, as outlined in Boon *et al*. (2011) and in the recent (January 2016) fire in the mangroves at Grantville on the eastern shore of Western Port, a fire initiated by a lightning strike. Fires can also occur within the peat layers of wetland sediments, and in this case can be almost impossible to control.

3.2.4 An overview of likely impacts

Table 5 summarises the findings reached by Voice *et al*. (2006) for mangroves and coastal saltmarsh at a whole-of-nation scale, and this information remains a good overview for describing likely impacts of climate change on these types of wetlands. Morris (2013) reported on likely impacts on Victorian seagrass-bed systems and her conclusions are shown in Table 6. Comparable information for the other types of coastal wetland identified in Table 1 are largely absent and thus indicate a significant knowledge gap.

Table 5: Likely impacts of climate change on coastal saltmarsh and mangroves. Source: modified from Voice *et al*. (2006, Table 4a).

Climate change driver	Likely impact	Sensitivity	Confidence	Known thresholds
Rise in mean sea levels	Vegetation loss	High	Good	Unknown
Extreme storms	Reduction in vegetation cover	Low-Medium	Good	Tolerant of storms unless threat is combined with other stressors
Increased waves and wind	Reduction in vegetation cover	Medium-High	Moderate	Impact greater when combined with sea-level rise
Increased CO_2 concentration in atmosphere	Increased primary productivity	Low	Good	Increase in productivity up to 30%; limited by water stress and salinity
Increased air temperature	Altered productivity and changes in species composition	Low-Medium	Good	Impact depends on latitude: larger impacts at

				southern latitudes
Decrease in humidity	Altered productivity and changes in species composition	High	Moderate	Unknown
Decreased rainfall	Reduced productivity, invasion of mangroves into saltmarsh, hypersalinity in saltmarshes	High	Good	Unknown
Increased rainfall	Increased productivity and diversity	Low	Good	Unknown

Table 6: Major vulnerabilities of Victorian seagrass-bed systems to various components of climate change. Source: Morris (2013, Table 9). Relative vulnerabilities are indicated by colours: high = light green, medium = light purple, low = dark purple. Where uncertainty in prediction exists: ••• = high, •• = moderate, • = low level of uncertainty; no dot indicated relative confidence in predictions.

Habitat	Region	Sea level & Tides	Ocean Currents	Upwelling	Temperature	Salinity	Waves	CO_2 & Acidification	Rainfall and Runoff
Intertidal	Western	•	•	•••	•		•••	••	••
	Central	•	•••	•••	•		•••	••	••
	Embayments	•	•••	•••	•	•	•••	•••	••
	Eastern	•	••	•••	•		•••	••	••
Shallow Subtidal	Western	•	•••	•••	•		•••	••	••
	Central	•	•••	•••	•		•••	••	••
	Embayments	•	•••	•••	•	•	•••	•••	••
	Eastern	•	••	•••	•		•••	••	••
Deep Subtidal	Western		•••	•••	•••		•••	••	••
	Central		•••	•••	•••		•••	••	••
	Embayments		•••	•••	•••	•	•••	•••	••
	Eastern		••	•••	•••		•••	••	••

3.3 Climate change projections and scenarios

3.3.1 Australian climate change projections

In 2015 CSIRO and BOM released climate change projections based on international climate change research for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) and a large body of climate research undertaken for the Australian region in recent years. These projections supersede those released by CSIRO and BOM in 2007.

The climate change projections were developed for eight regions (clusters), with some further sub-division (sub-clusters) (Figure 8). The Victorian coastline falls within the Southern Slopes cluster and the Southern Slopes Vic West and Southern Slopes Vic/NSW East sub-clusters (CSIRO-BOM, 2015c).

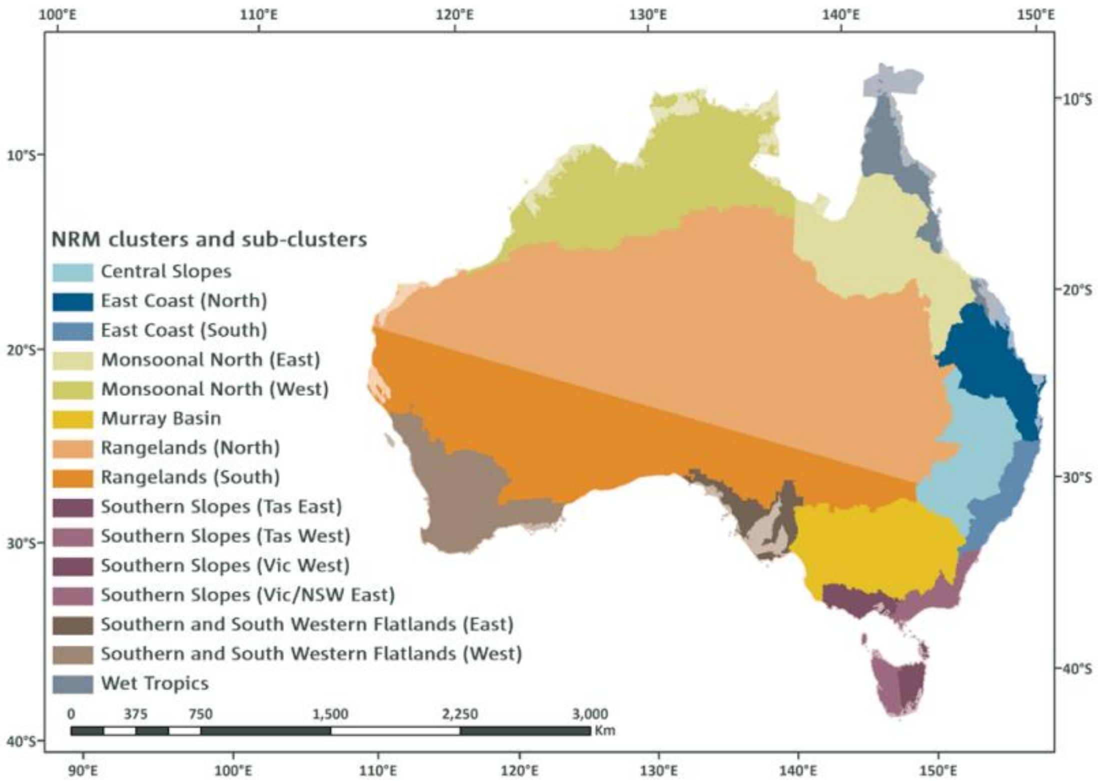


Figure 8: NRM clusters and sub-clusters (lighter shades denote coastal waters included in the clusters to encompass offshore islands). Source: CSIRO-BOM, 2015c.

Climate change projections are available for the four Representative Concentration Pathways (RCPs) used in the latest IPCC assessment. These represent different scenarios of radiative forcing (atmospheric warming) resulting from emissions of greenhouse gases, aerosols and land-use change. These RCPs include:

- **RCP8.5** – represents a future with effectively business-as-usual growth in emissions and atmospheric CO2 concentrations rising to 940 ppm by 2100.
- **RCP6.0** – represents lower emissions, achieved by application of some mitigation strategies and technologies. This scenario results in the CO2 concentration rising less rapidly than RCP8.5, but still reaching 660 ppm by 2100 and total radiative forcing stabilising shortly after 2100 (i.e. total radiative forcing continues to increase beyond 2100 in RCP8.5).
- **RCP4.5** – concentrations are slightly above those of RCP6.0 until after mid-century, but emissions peak earlier (around 2040) and the CO2 concentration reaches 540 ppm by 2100.
- **RCP2.6** – represents the most ambitious mitigation scenario, with emissions peaking early in the century (around 2020), then declining rapidly. The CO2 concentration reaches 440 ppm by 2040 then declines to 420 ppm by 2100.

A comparison of carbon emissions associated with each of the four RCPs is given in Figure 9. No particular scenario is deemed more likely than the others, however, RCP2.6, particularly, requires rapid changes to global emissions (CSIRO-BOM, 2015c).

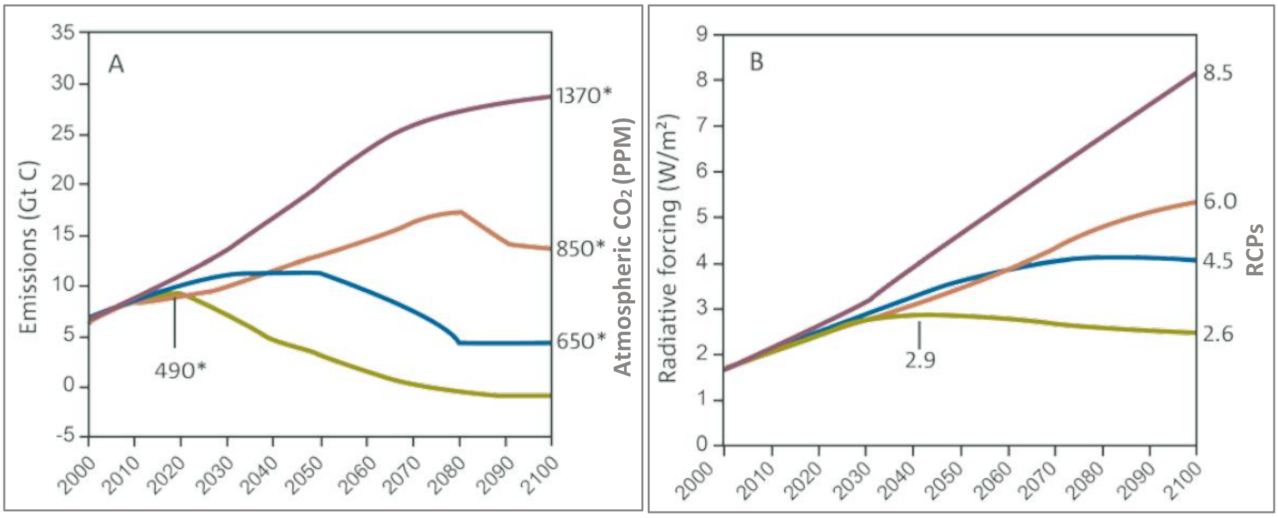


Figure 9: (A) Emission of carbon (in gigatonnes) for the different RCP scenarios used in the current CSIRO and BOM projections. The asterisked numbers show the atmospheric CO_2 equivalent level in parts per million (PPM). (B) Radiative forcing[9] for the different scenarios. The numbers on the right hand axis show the final forcing (W/M2) and equate to the names of the RCP scenarios. Colours represent RCPs: Green = RCP 2.6, Blue = RCP 4.5, Orange = RCP 6.0, Purple = RCP 8.5 (Source: CSIRO-BOM, 2015c).

Projected changes for the four RCPs can be explored for 14 future time periods at 5 year intervals between 2025 and 2090. Projections are based on 20 year periods centred on the year of interest.

3.3.2 Climate change projection for the Victorian coast

Projected changes to the climate in the coastal Victoria sub-clusters, the Southern Slopes Vic West and Southern Slopes Vic/NSW East sub-clusters, detailed in the CSIRO-BOM (2015a, b) report are summarised in Table 7.

Table 7: Climate change projections (magnitude of change) for the Southern Slopes – Vic West and Vic/ NSW East sub clusters (CSIRO-BOM, 2015a, b)

Climate change component	Climate change projection – magnitude of change
Rainfall	Less rainfall is projected in the cool season (winter and spring) with high confidence. Changes to summer and autumn rainfall are possible but less clear. For the near future (2030), natural variability is projected to dominate any projected changes. *Victoria West* The projected decrease in rainfall is up to 25% in winter and up to 45% in spring by 2090 under high emissions. By the middle of the century, and under high emissions, winter and spring changes are projected to be evident against natural variability. Changes to summer and autumn rainfall are possible but not clear, although there is a tendency for decrease in autumn. *Victoria/ NSW East* Projected reductions in winter rainfall are up to 30% in 2090 under high emissions. By the middle of the century, and under high emissions, winter changes are projected to be evident against natural variability. Changes to summer and autumn rainfall are possible but not clear.
Temperature	Continued substantial increases in mean, maximum and minimum temperatures are projected to occur (very high confidence) in line with the current understanding of the effect of further increases in greenhouse gas concentrations. *Victoria West*

[9] Radiative forcing (sometimes called 'climate forcing') is the net measure of incoming and outgoing radiation and is measured at the tropopause or top of the atmosphere. A negative forcing acts to cool the climate system, whereas positive forcing has a warming impact (CSIRO-BOM, 2015c).

	For the near future (2030), the annually averaged warming across all emission scenarios is projected to be 0.4 to 1.1°C above the climate of 1986–2005. By late in the century (2090), for a high emission scenario (RCP8.5) the projected range of warming is 2.4 to 3.8°C. Under an intermediate scenario (RCP4.5) the projected warming is 1.1 to 1.9°C. *Victoria/ NSW East* For the near future (2030), the annually averaged warming across all emission scenarios is projected to be 0.5 to 1.2°C above the climate of 1986–2005. By late in the century (2090), for a high emission scenario (RCP8.5) the projected range of warming is 2.7 to 4.3°C. Under an intermediate scenario (RCP4.5) the projected warming is 1.3 to 2.2°C.
Extreme temperature	More hot days and warm spells are projected with very high confidence. Fewer frosts are projected with high confidence. Extreme temperatures are projected to increase at a similar rate to mean temperature, with a substantial increase in the temperature reached on hot days, the frequency of hot days, and the duration of warm spells (very high confidence). Frost-risk days (minimum temperatures under 2°C) are expected to decrease (high confidence).
Extreme rainfall and drought	Increased intensity of extreme rainfall events is projected, with high confidence. However, the magnitude of the increases cannot be confidently projected. Time spent in drought is projected, with medium confidence, to increase over the course of the century.
Marine and coast	Sea surface temperature is projected to increase in the range of 1.6 to 3.4°C by 2090 under high emissions (RCP8.5). The sea will also become more acidic, with acidification proportional to emissions growth. Mean sea level will continue to rise and the height of extreme sea-level events will also increase (very high confidence). *Victoria West* There is very high confidence in future sea-level rise. By 2030 the projected range of sea-level rise for the western Victorian coastline is 0.08 to 0.18 m above the 1986–2005 level, with only minor differences between emission scenarios. By 2090, the intermediate emissions case (RCP4.5) is associated with a rise of 0.29 to 0.64 m and the high case (RCP8.5) a rise of 0.39 to 0.84 m. Under certain circumstances, sea-level rises higher than these may occur. *Victoria/ NSW East* There is very high confidence in future sea-level rise. By 2030 the projected range of sea-level rise for the eastern Victorian coastline is 0.07 to 0.17 m above the 1986–2005 level, with only minor differences between emission scenarios. By 2090, the intermediate emissions case (RCP4.5) is associated with a rise of 0.27 to 0.62 m and the high case (RCP8.5) a rise of 0.38 to 0.81 m. Under certain circumstances, sea-level rises higher than these may occur.
Other	A harsher fire-weather climate is expected to result from the projected warming and drying climate (high confidence). However, there is low confidence in the magnitude of the change due to uncertainty in rainfall projections and its seasonal variation. Potential evapotranspiration is projected to increase in all seasons as warming progresses (high confidence). An increase in solar radiation and a decrease in relative humidity is projected in the cool season through the century (high confidence). This will be influenced by changes in rainfall (and associated changes to cloudiness) and temperature. Changes in summer and autumn are less clear.

Table 8: Climate change projections (seasonal changes) for the Southern Slopes – Vic West and Vic/ NSW East sub clusters (CSIRO-BOM, 2015a, b)

Climate change component	Climate change projection – seasonal change
Rainfall	Rainfall declines are strongest in winter and spring. By 2090 most models project a decrease in winter rainfall in Victoria of -15 to +5% under RCP4.5 and -30 to +5% under RCP8.5. Spring rainfall is projected to decrease across every sub-cluster, with the strongest decline projected for western Victoria with a model range of -25 to -5% under RCP4.5 and -45 to -5% under RCP8.5 by 2090. There is little change projected in autumn and either increases or decreases in summer rainfall are possible in the Victorian Southern Slopes sub-clusters. For the near future (2030), natural variability is projected to dominate any projected changes.
Temperature	Projected temperature increases are similar in all seasons, with some models simulating to some extent larger increases in summer and autumn than in other season. Projected changes for both daily maximum and minimum temperature generally follow those of the mean temperature; although there is somewhat lower warming in daily minimum temperatures than daily maximum temperatures in autumn, winter and spring.

3.3.3 Applying the projections to identify exposure of climate change components to coastal wetlands

As described in Section 1.2 (also Section 2.1 of Volume One), the exposure component of the risk assessment estimates the likelihood of a given group or type of wetlands being subject to the given component of climate change (e.g. sea-level rise, increased concentration of atmospheric carbon dioxide). This is assessed based on the position of the wetland in the landscape (see Section 2) combined with current projections for the magnitude of each climate change component.

Given the similarity of RCPs in the year 2030 (Figure 9), CSIRO-BOM (2015c) recommends that it is necessary to select only one scenario for impact assessments at that timeframe. However beyond 2030, the four RCPs diverge and at least two scenarios should be considered (e.g. RCP4.5 and RCP8.5).

Based on these recommendations and to ensure consistency across climate change adaptation and mitigation projects in Victoria (e.g. EGCMA, 2015 and Spatial Vision, 2014) and in consultation with DELWP and regional managers, the following climate scenarios were adopted to assess exposure in this project and the DSF:

- 2050 – RCP 4.5 (moderate response to climate change and the time period provides a medium term planning perspective)
- 2070 – RCP 4.5 (moderate response to climate change and the time period that informs thinking about trajectories and potential longer-term impacts)
- 2090 – RCP 4.5 (moderate response to climate change and the time period that informs thinking about trajectories and potential longer-term impacts)
- 2050 – RCP 8.5 (worst case scenario, business as usual, response to climate change and the time period provides a medium term planning perspective)
- 2070 – RCP 8.5 (worst case scenario, business as usual, response to climate change and the time period that informs thinking about trajectories and potential longer-term impacts)
- 2090 – RCP 8.5 (worst case scenario, business as usual, response to climate change and the time period that informs thinking about trajectories and potential longer-term impacts)

These scenarios were agreed in consultation with DELWP and regional managers at the stakeholder workshop (22 July 2015).

3.3.4 Mapping of exposure of climate change components to coastal wetlands

Maps illustrating the exposure of coastal wetlands to each of the climate change components for the six climate change scenarios and three timeframes identified in Section 3.3.3 were developed for application in the vulnerability assessment and DSF using the approaches outlined below (maps are provided in Appendix F):

- Sea level – DELWP coastal inundation dataset10 for the 2030, 2070 and 2100 was applied to identify the locations likely to be exposed to changes in sea level. 2030 was used as a substitute for 2050 and 2100 for 2090 as these time frames were not available in the coastal inundation dataset. It should also be noted that the coastal inundation mapping does not distinguish between RCPs, therefore only one representative scenario for the sea level component of climate change was used.
- Rainfall – CSIRO-BOM (2015) modelled data from the Climate Change in Australia website11 was used to identify the likely change in rainfall across the Victorian coastal zone. There are a number of different models that are available for the use in vulnerability assessment, therefore the average change in rainfall of three representative models (documented on each map) was used, with the same models being applied for each RCP across the three timeframes to ensure consistency.
- Temperature – CSIRO-BOM (2015) modelled data publically available on the Climate Change in Australia website11 was used to identify the likely change in temperature across the Victorian coastal zone. There are a number of different models that are available for the use in vulnerability assessment, therefore the average change in rainfall of three representative models (documented on each map) was used, with the same models being applied for each RCP across the three timeframes to ensure consistency.
- Carbon Dioxide – all wetland flora and fauna will be exposed to the carbon dioxide concentration component of climate change and therefore no map has been developed for this climate change component.

4. How will coastal wetlands respond to climate change?

This section provides an assessment of the sensitivity of wetland types to different components of climate change, the critical point to stress is that different types of coastal wetland will respond in different ways to different components of climate change. As Freiss *et al*. (2012) have noted, not all (coastal) wetlands are the same when it comes to climate change. The EVC Coastal Saltmarsh Aggregate, for example, includes subsets that occur in lower-lying areas (e.g. Coastal Saline Grassland, dominated by *Distichlis distichophylla*) as well as subsets that occur on higher land, less often inundated and perhaps frequently freshened by rainfall (e.g. Coastal Tussock Saltmarsh dominated by *Austrostipa stipoides*). These two types of coastal saltmarsh will respond differently to alterations in sea level and storm surge. Similarly, the different types of seagrass beds represented by EVC 845 Sea-grass Meadow and EVC 854 Saline Aquatic Meadow, have a different range of characteristic taxa and occupying intertidal subtidal and ephemeral habitats. Not only will these likely respond in different ways to the various components of climate change, but it is quite possible that seagrass beds in different regions of the State and in different habitat types will respond differently too. Table 6 showed how variations may occur in different parts of the Victorian coastline. It is outside of the scope of the current study to tease apart such differences, but they should be borne in mind when interpreting the conceptual models and undertaking vulnerability assessments.

The following sections provide an assessment of the sensitivity and adaptive capacity of different wetland types to different components of climate change through the generation of conceptual models for each

[10] Available at www.data.vic.gov.au

[11] www.climatechangeinaustralia.gov.au

climate change component and generic sensitivity rankings for each wetland type. When considered together, these two components provide an indication of the likely outcomes of climate change for coastal wetlands. Table 9 provides a summary of these outcomes.

Table 9: Summary of likely outcomes of climate change for coastal wetlands

Climate change component	Likely outcomes
Increased sea level and storm surge	• More permanent inundation or increased frequency and duration of inundation of wetlands. • Change in salinity and water regime in wetlands due to saline intrusion. • Changes in vegetation distribution along the elevational gradient from the sea, with possible landward migration: – Conversion of currently intertidal seagrass beds to subtidal systems, and an increase in depth of subtidal systems. – Replacement of areas currently vegetated with saltmarshes by more inundation-tolerant mangroves. – Replacement of areas currently vegetated with glycophytic (e.g. *Phragmites australis*) or brackish-water plants (e.g. *Melaleuca ericifolia*) by saltmarshes. – Changes in the floristic distribution of saltmarsh taxa along the elevational gradient from the sea. • Excessive sedimentation and erosion along shoreline impacts mangroves and coastal saltmarsh, effects can occur at both the establishment phase of young plants and adult plants. • Changes in distribution of plant propagules, via altered currents and tidal patterns. • Breakage of young plants by wind or waves during their establishment. • Modification of patterns and rates of coastal sedimentation and erosion, affecting the area suitable for mangrove or saltmarsh colonisation. • Geomorphic changes to estuary mouth and coastal barriers/ dunes due to sea level rise and storm surges (e.g. increased rates of erosion). • Saline intrusion into the upper estuary and lower freshwater reaches of the rivers due to increased sea levels and storm surge activity. Causes rise in saline conditions along riparian zone. • Saline intrusion into groundwater results in a changed wetland environment. • Increased pressure from weed invasion.
Increased carbon dioxide concentration	• Competitive interactions between plants will be affected. C3 plants will be advantaged (e.g. mangroves and most but not all saltmarsh plants and mangroves. • Acidification of coastal waters causing major impacts on phytoplankton and possibly on submerged angiosperms such as seagrasses. Aquatic organisms that build calcareous or carbonate shells from aragonite (e.g. crustaceans) and some macroalgae that have calcified tissues may also be affected. • Increased pressure from weed invasion.
Decreased rainfall	• Change in water and salinity regime due to reduced freshwater inflows, decreased rainfall and increased flooding causing longer periods between freshwater inundation and development of hypersaline conditions. • Replacement of areas of coastal wetlands currently vegetated with glycophytic (e.g. *Phragmites australis*) or brackish-water plants (e.g. *Melaleuca ericifoia*) by saltmarshes as a result of increased salinity. • Changes in primary productivity and distributions of mangrove communities, probably towards increased vigour and a wider distribution. • Modification of patterns and rates of coastal sedimentation and erosion, with effects on the area suitable for mangrove or saltmarsh colonisation. • Saline intrusion into groundwater due to reduced groundwater recharge results in a changed wetland environment. • Saline intrusion into the upper estuary and lower freshwater reaches of the river due to

	reduced rainfall/catchment runoff. • Increased pressure from weed invasion.
Decreased temperature	• Impacts on flowering and germination of plants and the breeding success of invertebrates, fish and birds. • Disruption of life histories of stenothermal invertebrates and fish, with consequences for growth, mortality and secondary productivity. • Increased rates of primary production by saltmarshes and mangroves, unless other factors (e.g. hypersalinity, lowered nutrient availability, etc) intervene. • Changes in primary productivity and distributions of mangrove communities, probably towards increased vigour and a wider distribution. • Change in water and salinity regime due to increased evaporation losses causing reduction in permanence and an increase in ephemerality in coast wetlands. • Increased pressure from weed invasion.
Temperature	Projected temperature increases are similar in all seasons, with some models simulating to some extent larger increases in summer and autumn than in other season. Projected changes for both daily maximum and minimum temperature generally follow those of the mean temperature; although there is somewhat lower warming in daily minimum temperatures than daily maximum temperatures in autumn, winter and spring.

4.1 Conceptual models

4.1.1 Sea-level rise and storm surges

The CSIRO-BOM (2015a, page 6) report concluded that:

> There is *very high confidence*[12] in future sea level rise. By 2030 the projected range of sea-level rise for the cluster coastline is 0.07 to 0.19 m above the 1986–2005 level, with only minor differences between emission scenarios. As the century progresses, projections are sensitive to concentration pathways. By 2090, the intermediate emissions case (RCP4.5) is associated with a rise of 0.27 to 0.66m and the high case (RCP8.5) a rise of 0.39 to 0.89 m[13]. Under certain circumstances, sea-level rises higher than these may occur.

The possibility that sea-level rise may be greater than projected on the basis of the most recent IPCC reports has been suggested in a number of papers. Steffen *et al*. (2009a, page 90)concluded that ' … the IPCC sea level rise projection of up to about 1 m by 2100 may be far too low in the light of its own projected temperature change.' The CSIRO-BOM (2015a, b) assessment indicates that the rise in eustatic sea levels could be as low as 0.3 m or as high as 0.88 m. It is possible that even the higher estimates are too low. Among the most compelling evidence for accelerating sea-level rise is that presented by Rahmstorf *et al*. (2007), who argued that the sea-level rise by 2100 would likely be of the order of 0.5 to 1.4 m. Rahmstorf (2010) noted that the measured rate of average sea-level rise since high-resolution satellite measurements became available in 1992 was ~80% faster than the average rate predicted by IPCC models (3.4 mm $year^{-1}$ versus 1.9 mm $year^{-1}$). He calculated that sea levels could rise by over 1.10 m by 2090. More recently, Jevrejeva *et al*. (2014) placed a likely upper limit of 1.80 m on sea-level rise by 2100. It should be noted too that the rise in sea levels will not be limited to increases up to the end of the 21st century. Even if CO_2 emissions were to cease immediately, sea levels would continue to rise for centuries because of the slow but continual warming of the oceans and contraction of the Greenland ice sheet.

[12] Italics in original

[13] These are median values.

Eustatic sea level

Changes in sea level exert an almost overwhelming influence on coastal wetlands (Woodroffe & Davies 2009), and it is this topic that has received most attention by studies examining likely impacts of climate change on coastal wetlands and their plant communities. These studies suggest that increased sea levels will have severe ecosystem-wide impacts on coastal wetlands, including:

- Conversion of currently intertidal seagrass beds to subtidal systems, and an increase in depth of subtidal systems.
- Partial or complete inundation (and possible loss) of existing saltmarsh and mangrove communities.
- Replacement of areas currently vegetated with saltmarshes by more inundation-tolerant mangroves.
- Replacement of areas currently vegetated with glycophytic (e.g. *Phragmites australis*) or brackish-water plants (e.g. *Melaleuca ericifolia*) by saltmarshes.
- Changes in the floristic distribution of saltmarsh taxa along the elevational gradient from the sea.
- Affect the distribution of plant propagules, via altered currents and tidal patterns.
- Modify patterns and rates of coastal sedimentation and erosion, with effects on the area suitable for mangrove or saltmarsh colonisation

Although the information base is still rather small, there are a number of studies that addressed the role of sea-level rise in mangrove development and others that make some predictions about the likely impact of future sea-level rise on these types of ecosystems (e.g. Gilman *et al*. 2007, 2008; Woodroffe & Davies 2009). It is clear from the stratigraphic record that mangroves have survived rapid sea-level rise in the past and such knowledge provides a basis for predicting how coastal wetlands will respond to sea-level rises that will occur as a result of climate change. The main response of mangroves in past periods of rising sea levels has been for the plants to migrate landwards. The issue today, of course, is that the extensive development of the hinterland will often preclude such migration. This topic and other related to it is discussed in Section 5.

With regard to other types of coastal wetlands, early assessments of sea-level rise concluded there would be a large-scale loss of wetland habitat across the globe (see the review by Pratolongo *et al*. 2009).

There is now some information on how coastal wetlands in south-eastern Australia might respond to sea-level rise (e.g. Laegdsgaard 2006; Boon *et al*. 2010; Prahalad *et al*. 2011; Rogers *et al*. 2012, 2014). A series of reports was published by the Australian Greenhouse Office in 2006 on the impacts of climate change on coastal and marine ecosystems (Steffen *et al*. 2006a, b). Voice *et al.* (2006) concluded that, although the vulnerability of saltmarsh and mangrove communities varied around the Australian coast and with species, the productivity was likely to be negatively affected by climate change. They noted that predicting the impacts of climate change on coastal wetlands was made more difficult by the lack of ecological information, and that the available information was scattered across diverse and often hard-to-obtain sources. Boon (2012) came to a similar conclusion for coastal wetlands in south-eastern Australia. The three conceptual models developed for this project on sea-level rise impacts must, therefore, be interpreted with caution.

The first conceptual model (Figure 10) shows the current-day zonation of vegetation types with elevation from the sea in coastal Victoria.

As shown in Figure 3, most seaward is the mangrove zone, followed by a saltmarsh zone, then often by a band of Sea Rush (*Juncus kraussii*), then by a band of Swamp Paperbark (*Melaleuca ericifolia*),or in western Victoria, various tea-tree taxa (*Leptospermum* spp.). Behind them is often the terrestrial vegetation dominated by various *Banksia* and *Eucalyptus* spp. forming the canopy layer. Freshwater wetlands of various sorts can occur within this nominally terrestrial band, and they too must be considered as coastal wetlands, as outlined in Section 2.3. Figure 11 shows an on-ground example of this zonation, at Sperm Whale Head in the Gippsland Lakes.

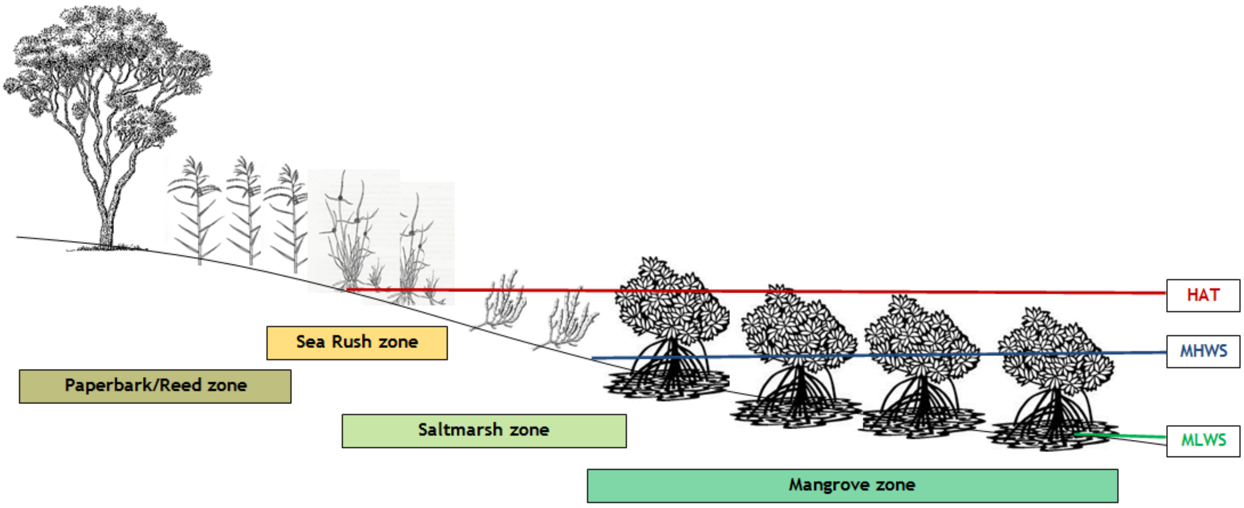


Figure 10: Conceptual model of current-day zonation of vegetation types with elevation from the sea in coastal Victoria

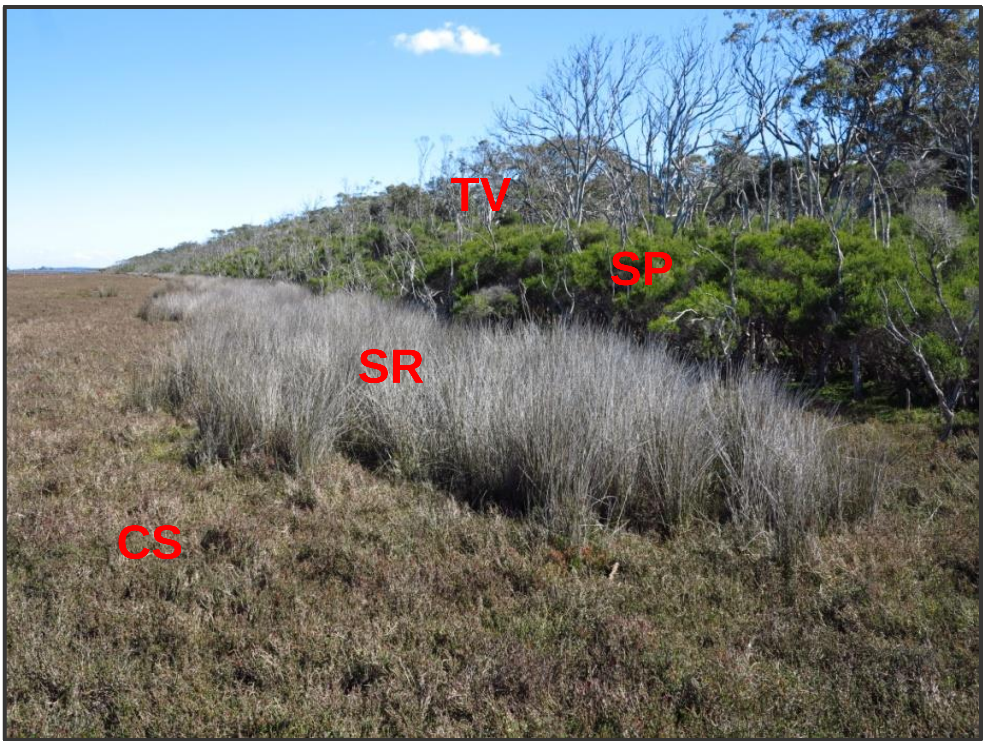


Figure 11: Plant zonation at Sperm Whale Head in the Gippsland Lakes, showing the seaward fringe of coastal saltmarsh (CS) at the lowest elevation, the mid-grey band of Sea Rush (SR), the band of Swamp Paperbark (SP) at higher elevations, and the terrestrial vegetation dominated by Banksia and Eucalyptus (TV). The sea is to the left of the photograph. Photograph taken by Paul Boon, September 2014.

The second conceptual model (Figure 12) shows the likely impact on coastal wetlands and their elevational zonation if eustatic sea levels rise in a regular way. The assumption is that if sea levels rise by an average of 0.5 m, the zonation of plants will remain roughly the same as it is today, but will be pushed back an equivalent amount into the hinterland. The most obvious impact is that coastal wetlands will be inundated more frequently and more deeply with seawater. The most low-lying areas may become permanently inundated. The simplest prediction is that saltmarshes would be replaced by mangroves, and mangroves by seagrasses. In more elevated positions, the frequency of inundation from either storm surges or floods will increase and would be expected to have profound effects on the water and salinity regimes in the wetlands. Whether or not this is currently possible given the constraints of hinterland development (e.g. sea walls) is unclear. This model is often described as a simple bath-tub model and was used, for example, to describe the effects of a rise in eustatic sea levels on the peripheral vegetation of Port Phillip Bay by Boon *et al*. (2010).

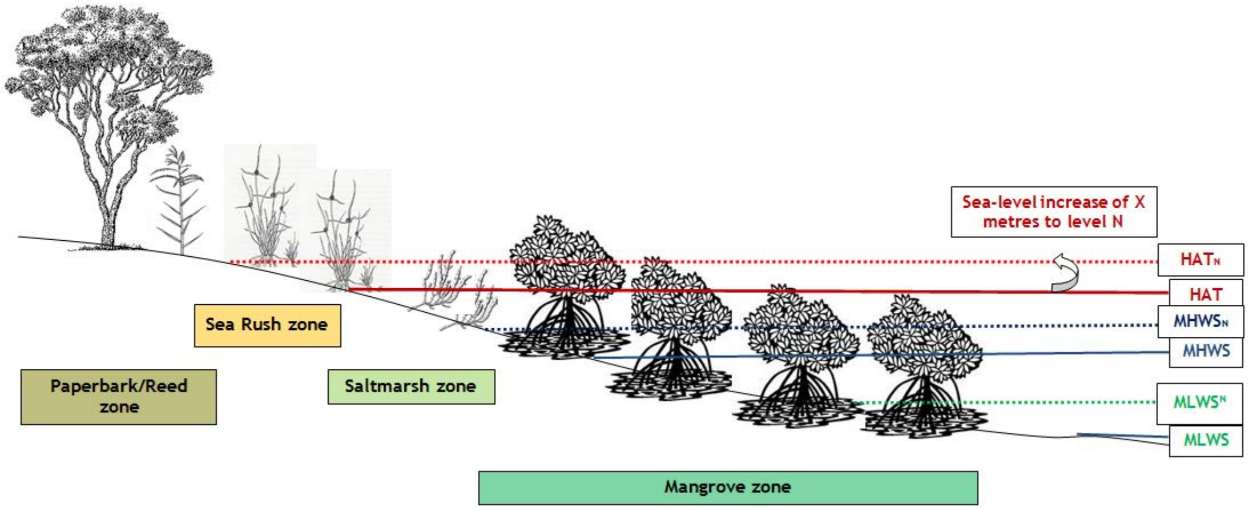


Figure 12: Conceptual model of the impact of rise in eustatic sea level on coastal wetlands

More recent studies have taken an increasingly sophisticated approach and have recognised that the issue is not so much sea-level rise per se but changes in *relative* sea levels that will be the fundamental determinant of responses (Morris *et al*. 2002). In other words, if coastal wetlands can maintain their surface elevation, they can keep up with – as opposed to catch up with (Woodroffe & Davies 2009) – sea-level rise (Pratolongo *et al*. 2009). This response of wetland sediment elevations to altered hydrological regimes is often ignored, perhaps because it is assumed that wetland vegetation is a passive player in the evolution of coastal environments. This assumption has led to the widespread use of simple bath-tub models (e.g. Boon *et al*. 2010) to predict the impacts of increased sea levels on coastal wetlands (e.g. conceptual model in Figure 12). The predictions raised by these simple models are naïve and probably over-estimate the adverse effects that can be expected from rises in eustatic sea level. In a recent assessment, for example, Rogers *et al*. (2012) calculated that simple 'bath-tub' modelling indicated a loss of about 6% in the extent of coastal wetlands along the Hunter River estuary on the central coast of New South Wales. If realistic rates of change in sediment elevation were included in the model, it was estimated that there may be a 16% increase in the area of coastal land suitable for colonization by mangroves and saltmarsh. It is, therefore, imperative that models of potential sea-level rise impacts on peripheral vegetation include rates of likely sediment elevation responses.

The elevation of sediments in coastal wetlands is controlled by two processes:

- Sediment trapping (e.g. via sedimentation) and/or sediment loss (e.g. erosion)
- The accumulation (or loss) of organic material built up by the roots and rhizomes of fringing vegetation.

The latter process is a result of the high rates of below-ground productivity of coastal plants, and can be due to accumulations either of dead plant remains (e.g. peat) or expansion in the volume of living plant roots and rhizomes. The rate of below-ground accumulation of dead organic matter is controlled to a large degree by water-logging, and this is controlled by inundation patterns (Figure 13).

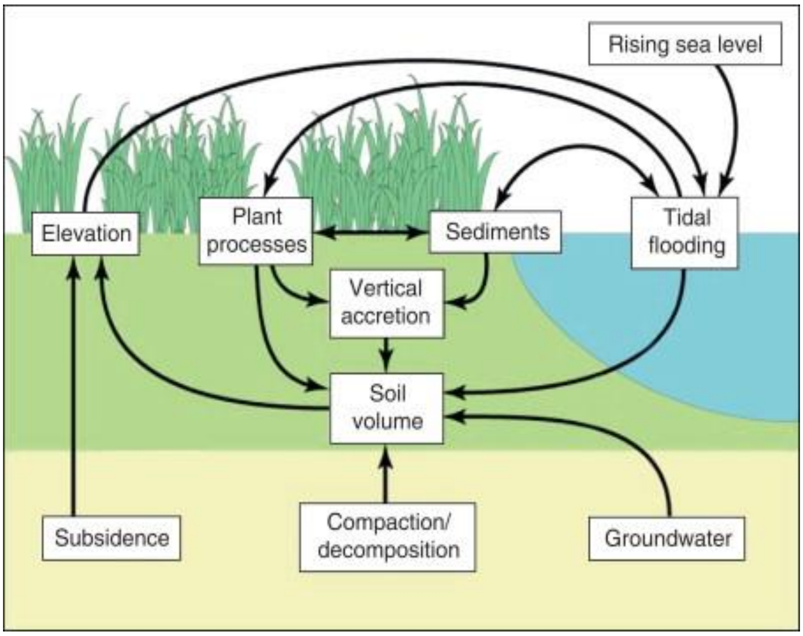


Figure 13: Interactions between above and below ground productivity, sediment deposition, peat accumulation, tidal inundation and groundwater behaviour in controlling sediment elevations in coastal wetlands (Spencer & Möller 2011).

If Victorian coastal wetlands can maintain increases in sediment elevations that match (or even exceed) the average rate of eustatic sea-level rise, then they will not be inundated to the extent suggested in the model presented in Figure 12. A refined model (Figure 14) shows the situation in which sediment elevations keep track with rises in sea levels. Sediment elevations could be maintained by either of the processes outlined above (sediment trapping or accumulation of organic matter). It is most likely to occur in the mangrove fringe because mangroves are inundated twice daily by the tides and so can accumulate sand and other material deposited by each tide. Saltmarshes, in contrast, are inundated only by spring tides, and more elevated wetland vegetation communities only by even high tides, such as the highest astronomical tide. For these more elevated types of wetlands, tidal deposition of suspended material is not an option for maintaining sediment levels, and the only mechanism is the deposition of below-ground material, which increases soil volume.

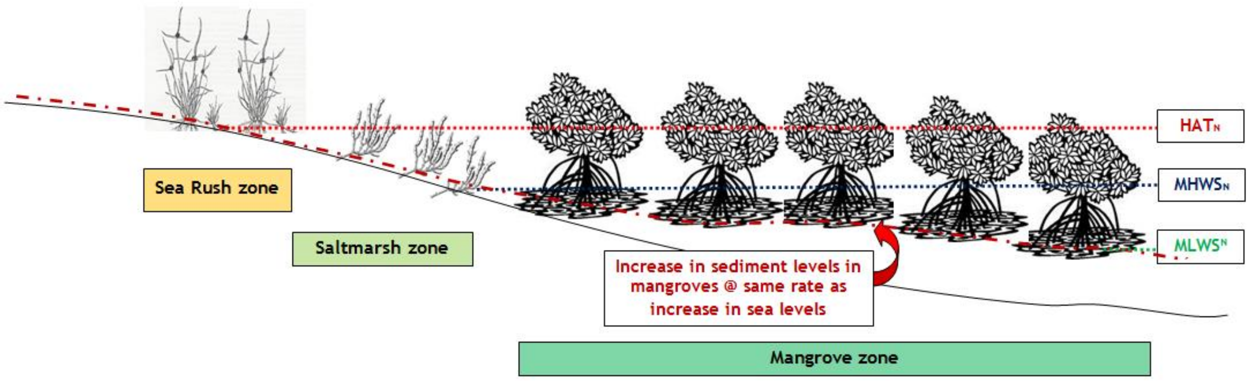


Figure 14: Conceptual model of the impact of eustatic sea level rise on coastal wetlands where sediment elevations keep track with rises in sea levels.

Nevertheless, it is naive to assume that the only response of coastal wetlands to higher eustatic sea levels is retreat. If the rate at which sediment elevation increases matches the rate at which the sea is rising, some types of coastal wetlands (e.g. mangroves) may be maintained in the same position. The wetlands that lie behind them may not have the same capacity, and so could still be squeezed behind a front of advancing mangroves. This is shown in Figure 14 by a narrowing of the saltmarsh and Sea Rush zone.

Storm surge

None of the conceptual models presented above makes explicit reference to the impact of increased frequency and severity of extreme events. Storms and other extreme events will have a diverse range of geomorphological impacts on coastal wetlands (Cahoon 2006). Coastal erosion will be most severe during extreme events, sandy coastlines will be particularly susceptible to storm surges (Walsh 2004). The erosion of sandy beaches could have particularly strong impacts on the breaching of coastal barriers that currently protect coastal lagoons from the ocean. Such sandy dunes do not normally survive overtopping by high-intensity storms (Nott and Hubbert 2003) and, for the Gippsland Lakes, it has been predicted that the seaward line of dunes could be breached by the combination of higher mean sea levels and storm surges (Sjerp 2007). If this were to happen, inundation and salinity regimes of the wetlands in Gippsland's Lake Reeve, for example, would be affected greatly. As noted in Section 3.2.1, shorelines on unconsolidated sediments (e.g. sand, silt, and clay), organic deposits or on other poorly consolidated material (e.g. weakly indurated sandstone or mudstone), would be most sensitive to coastal erosion. It is often these types of shoreline, rather than say granitic shores or limestone cliffs, that support coastal wetlands. As an example, in his analysis of the impacts of higher sea levels on Port Phillip Bay, Bird (2006) argued that increased sea levels, combined with the associated increase in wave action and erosion, would see the loss of the Mud Islands (and their saltmarshes) near the entrance of the Bay.

The impacts of extreme events on fringing vegetation is most likely to be seen via two processes: i) the landward penetration of sea water, with resultant effects of inundation and soil salinity; and ii) altered processes of sediment deposition or erosion. Marine incursions into coastal wetlands have occurred across large parts of northern Australia, including in Kakadu National Park, with poor outcomes for nominally freshwater vegetation such as *Melaleuca* woodlands. Often tidal creeks act as the medium for such marine incursions. Regarding the second process, it is well known that mangroves and coastal saltmarsh are susceptible to excessive sedimentation and to erosion, and the effects can occur at both the establishment phase of young plants and on adult specimens. Young plants are particularly susceptible to breakage by wind or by waves during their establishment; wind and wave-induced disturbance and toppling were identified as significant factors limiting the establishment of young mangrove plants along the eastern shore of Western Port by Kirkman and Boon (2012).

Detailed investigations have been undertaken for two coastal regions of Victoria of possible impacts of extreme events and storm surges on the coast: i) Western Port (Western Port Greenhouse Alliance 2008); and ii) eastern Victoria, including Corner Inlet/Nooramunga and the Gippsland Lakes (McInnes *et al*. 2005 a, b, c; 2006; Sjerp 2007).

The findings for Western Port are summarised below as an example of the likely impacts created by extreme events on coastal wetlands. Mean sea-level rises of 0.17 m and 0.49 m are projected for Western Port by 2030 and 2070, respectively (Western Port Greenhouse Alliance 2008). These are relatively small when compared with the effects likely to result from extreme events such as storm surges. Storm tides at Cowes (on Phillip Island), for example, could reach 2.29 m by 2030 and 2.74 m by 2070. Not only will storm surges be higher, but they will be more frequent. It was projected that storm surges with a current return interval of 1:100 years would have a new average return interval of only 1:40 or even 1:6 years by 2030, and 1:20 or 1:1 years by 2070. In other words, what is currently a severe storm that occurs only once a century could become an annual event by 2070. Linked with the increase in the severity and frequency of storm surges is a projected increase in extreme rainfall and extreme winds.

In summary, an increased incidence (and possibly increased severity) of severe weather events could have the following ecological impacts on coastal wetlands:

- Increased severity and incidence of storm surges, which could breach coastal sand dunes, lead to increased rates of erosion, and subject landward areas to additional inundation by seawater.
- Increased incidence and severity of riverine floods, with impacts on the inundation by freshwaters of coastal wetlands and, in some locations, ‘back-up’ of marine or brackish water into other wetlands.
- Increased incidence and severity of droughts, with potential impacts on freshwater inundation, evaporation and creation of hypersaline conditions in saltmarshes.

- Increased incidence of flashy discharge, with implications for sudden and rapid inundation of coastal wetlands, increased erosion in the catchment and sedimentation, increased nutrient loads, and increased scouring of channels and wetland basins.

4.1.2 Carbon dioxide concentrations

Increased concentrations of atmospheric CO_2 have a direct impact on global climate by intercepting infra-red radiation and contributing to increased atmospheric temperatures. The ecological consequences of this element of climate change for coastal wetlands are summarised in Figure 15.

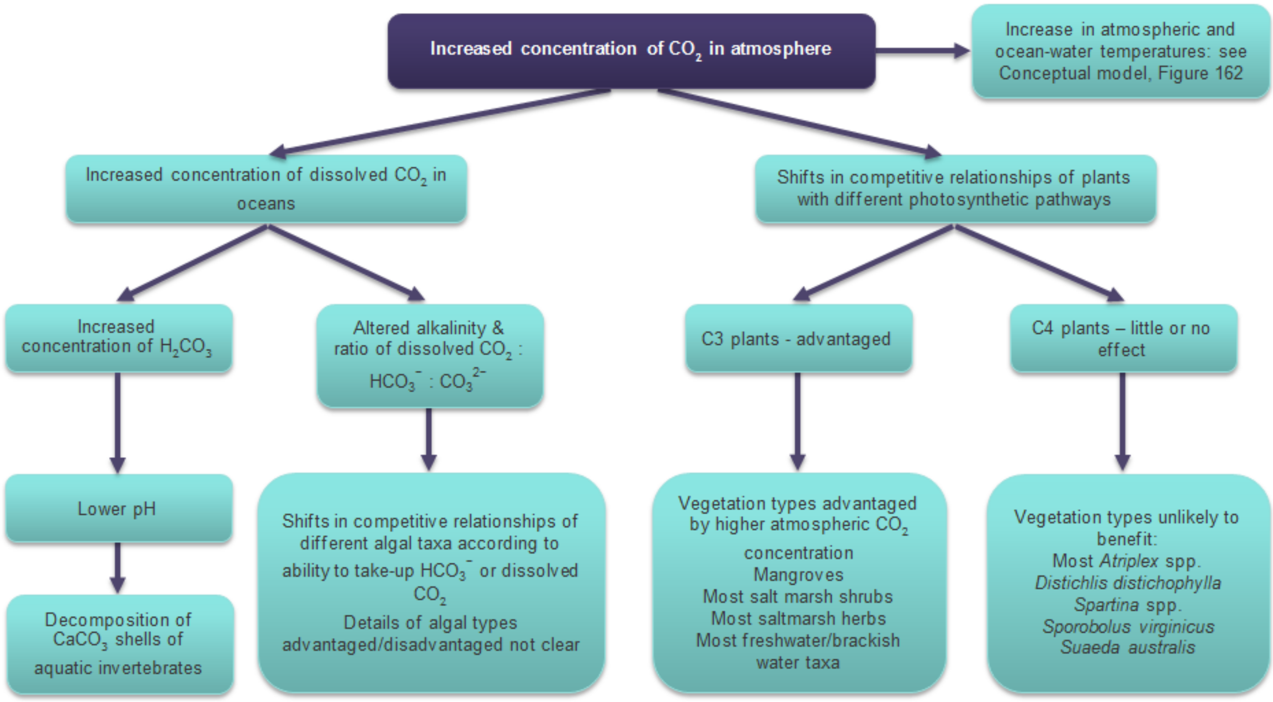


Figure 15: Conceptual model of the impact of increased concentrations of atmospheric CO_2 on coastal wetlands

As outlined in Table 4, increased concentrations of atmospheric CO_2 have two other consequences for coastal wetlands. The first involves acidification of coastal waters as the partial pressure of CO_2 increases in the atmosphere and fundamental changes occur in the carbon cycle of the oceans, especially to the chemistry of aragonite, one of the two common and naturally occurring crystalline forms of calcium carbonate, $CaCO_3$. The resultant fall in ocean-water pH is expected to have major impacts on phytoplankton and possibly on submerged angiosperms such as seagrasses, effects mediated by the differential uptake of dissolved CO_2 versus bicarbonate HCO_3^- by different types of submerged plant (Poloczanska *et al*. 2007; Steffen et al. 2009a, b). Acidification will also have major impacts on aquatic organisms that build calcareous or carbonate shells from arogonite, such as crustaceans and molluscs. Some macroalgae also have calcified tissues, and acidification is likely to affect them as well (Nelson 2009).

The second, and likely more significant, mechanism is that increased concentrations of atmospheric CO_2 will affect competitive interactions between plants. Plants fix atmospheric CO_2 in different ways using different metabolic pathways, each of which has a competitive advantage in different environments:

- C3 photosynthesis, the pathway used by most terrestrial plants for photosynthesis.
- C4 photosynthesis, notably common in warm-season grasses, and advantageous in warmer climates and under water stress.
- CAM photosynthesis, which occurs in relatively few taxa but is strongly advantageous under extreme drought stress. It is often associated with succulence.

Plants with the C3 photosynthetic pathway include most − but not all − species of vascular saltmarsh plants in south-eastern Australia, plus the sole mangrove species present in Victoria, *Avicennia marina*. They have high rates of photorespiration and a variable photosynthetic capacity (Table 10). In contrast, plants with the C4 photosynthetic pathway include many grasses (e.g. some *Distichlis* and *Sporobolus* spp.), plus an assortment of other monocots such as *Spartina* and, some dicots such as *Atriplex spp*. and *Suaeda australis*). They show little photorespiration and at full sunlight can be twice as productive as C3 plants. Because of their more efficient use of CO_2, C4 plants use less water to achieve the same rate of primary production as C3 plants. As the optimal temperature for C4 plants is usually greater than that of C3 plants, a warmer and drier climate thus might be expected to favour C4 plants. The complication is that the C3 plants require higher CO_2 concentrations than do C4 plants. Thus a complex interaction among plant taxa with different photosynthetic pathways can be expected, according to differential responses to CO_2 concentrations, temperature, water stress and, probably, nutrient availability.

Table 10: Comparison of photosynthetic and productivity characteristics of C3 and C4 plants (modified from Bonan 2002, Table 9.2)

Characteristic	C3 Plant	C4 Plant
Photorespiration	High	Low
Photosynthetic capacity	Low to high	High to very high
Light saturation	Intermediate light intensities	None or extremely high light intensities
Water use efficiency	Low (1–5 g kg-1 H2O)	High (3–5 g kg-1 H2O)
Optimum temperature for photosynthesis (°C)	15–25	30–45
CO_2 compensation point (ppm)	30–50	0–10

In the flora of coastal wetland plants of south-eastern Australia there is a mix of C3, C4 and CAM plants (Table 11). Most taxa are C3, but a number, including saltbushes *Atriplex* spp, and the grasses *Distichlis* and *Sporobolus* spp. are C4. The potentially serious weed *Spartina* is also a C4 plant. Adam (2008) concluded that it was almost certain that there would be changes in the balance between C3 and C4 plants in coastal saltmarshes as a result of climate change. There is some experimental evidence for this conclusion; Gray and Mogg (2001) reported that higher temperatures and increased ambient CO_2 concentrations favoured the C3 *Puccinellia maritima* over the C4 *Spartina anglica* in Northern Hemisphere saltmarshes.

Table 11: Photosynthetic pathways of some plant species occurring in Victorian coastal wetlands (Boon et al. (2011), using data collated by Dr Steve Sinclair, Arthur Rylah Institute, Melbourne).

C3	C4	CAM
Angianthus preissianus	*Atriplex cinerea*	*Disphyma clavellatum*
Austrostipa stipoides	*Atriplex paludosa*	
Avicennia marina	*Distichlis distichophylla*	
Gahnia filum	*Spartina spp.*	
Lawrencia squamata	*Sporobolus virginicus*	
Puccinellia spp.	*Suaeda australis*	
Sarcocronia quinqueflora		

Tectocornia arbuscula
Tecticornia halocnemoides
Tecticornia pergranulata
Wilsonia backhousei
Wilsonia humilis
Wilsonia rotundfolia

4.1.3 Temperature

Figure 16 shows the conceptual model developed to illustrate the impacts of higher air and water temperatures on coastal wetlands. Increases in air temperatures are likely to have many phenological impacts on the biota of coastal wetlands, including:

- Impacts on flowering and germination of plants and the breeding success of invertebrates, fish and birds.
- Disruption of life histories of stenothermal invertebrates and fish, with consequences for growth, mortality and secondary productivity.
- Increased rates of primary production by saltmarshes and mangroves, unless other factors (e.g. hypersalinity, lowered nutrient availability, etc) counteract this.
- Facilitated invasion by weeds that are currently temperature-limited, e.g. [*]*Baccharis halimifolia* or **Paspalum vaginatum*, or will be advantaged by increased inundation (e.g. **Spartina* spp.).

Three specific temperature related impacts can be envisaged. The first relates to the differential response of C3, C4 and CAM plants to higher temperatures. This effect is additional to the effect of increased atmospheric CO_2 concentrations on plants, as discussed in the earlier conceptual model. C3, C4 and CAM plants differ in their responses to temperature, and C4 plants tend to have a higher optimum temperature for photosynthesis than do C3 plants (Table 10). This difference means that, on the whole, plants with the C4 metabolic pathway can be expected to grow more quickly under a warmer climate than would C3 plants. This difference will, however, be offset to an extent by the frost-sensitivity of mangroves, a response discussed next.

[*] non-native species

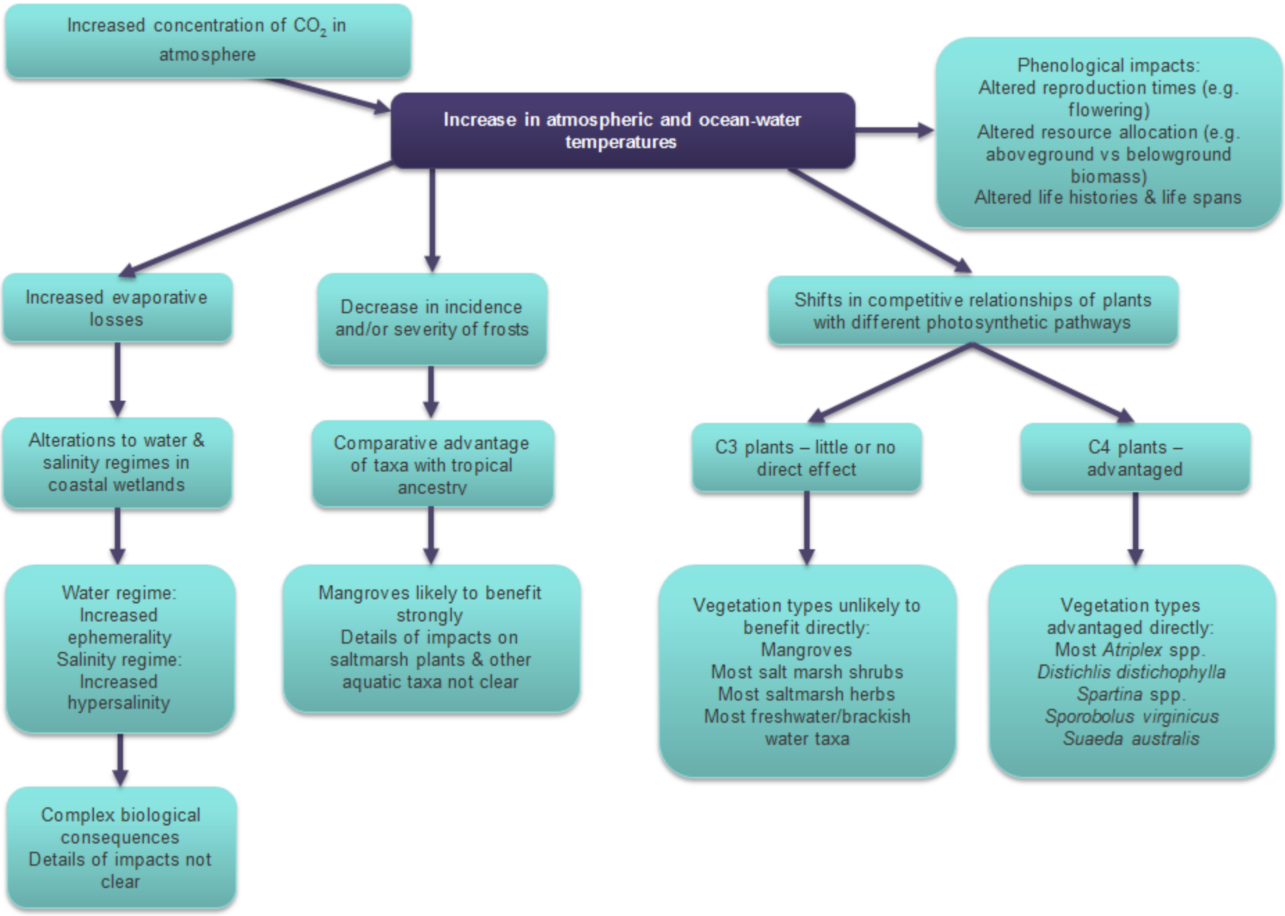


Figure16: Conceptual model of the impact of higher air and water temperatures on coastal wetlands

The second relates to an increase in winter temperatures and a decrease in the incidence and severity of frosts in south-eastern Australia. Sjerp (2007) reported that there would be at least a 40% reduction in the number of frost days in West Gippsland, and a total loss of frost days in East Gippsland, by 2070. Low winter air temperatures and/or the high frequency of frosts have been suggested as factors that control the southerly distribution of the mangrove *Avicennia marina* in Victoria (Oliver 1982). Relieved of their current limitation by cold and/or frost, mangroves could expand their distribution, and possibly also their productivity, across southern Victoria where there are suitable sites for colonisation. Earlier in the report the example of the recent (post-1980) appearance of mangroves in the Gippsland Lakes was reported as a possible result of climate change. The now often-observed 'invasion' of mangroves into coastal saltmarsh across south-eastern Australia is another (Saintilan and Williams 1999).

The third relates to the effect of higher temperatures (and likely but less well defined changes in rainfall) on water and salinity regimes in coastal wetlands. The most recent CSIRO-BOM projections for temperature is an increase of 0.7−3.1ºC by 2090, although the 90th percentile confidence limit for the RCP8.5 high-emissions scenario is 4.0ºC (CSIRO-BOM 2015a, b). Changes in rainfall are projected with less certainty, although reductions of between 7 and 31% (medians) are predicted (CSIRO-BOM 2015 a, b). The expected outcome of the interaction of the two factors (increased temperature and rainfall) is a reduction in permanence and an increase in ephemerality in coastal wetlands, with likely associated shifts to hypersaline conditions. Depending on changes in flood regimes, coastal wetlands may experience greater extremes in water and salinity regimes, with higher temperatures and lower rainfall driving less permanent water regimes and higher salinities, and more frequent severe floods driving inundation of larger areas of coastal floodplains than occur at present. As noted earlier, the combination of higher air temperatures and less rainfall will alter fire risk, with impacts possible both at the catchment scale and at the level of the individual wetland.

Increased temperatures may also have consequences for the spread of exotic taxa in coastal wetlands. The recent spread of *Spartina anglica* into new parts of the Wadden Sea (The Netherlands) was attributed by Loebl *et al*. (2006) at least in part to increasing temperature. Their study showed that *Spartina anglica*, after being introduced to the Wadden Sea in 1927, spread rapidly across sheltered shorelines in ensuing decades. It was anticipated that rising sea levels and increased storm activity would limit its further spread as niches available for further colonization narrow. However, many new sites have become infested since 1985 with dense monotypic swards of *Spartina anglica*, and the renewed spread coincided with a shift in local temperatures after ~1987. The critical physiological thresholds of 4ºC for seed germination and 7ºC for photosynthesis were exceeded often after 1987 and the warmer springs, in particular, were thought to have been responsible for increased rates of germination, vegetative growth and geographic spread. In a more recent paper, Nehring & Hesse (2008) came to similar conclusions.

Increasing temperatures may particularly favour one weed species in the current saltmarsh flora, **Paspalum vaginatum*. This species is a member of a genus with a predominantly warm-temperate and tropical distribution, and changes to a warmer climate might extend its range across the State. (It is currently rare outside of East Gippsland.) A second species that may respond in a similar way is the shrub **Baccharis halimifolia*, which is a major threat to saltmarsh vegetation in more coastal wetlands in Queensland and the north and central coasts of New South Wales. It is reported by Saintilan (2009) to be extending its distribution towards the south in that State. The natural distribution of **Baccharis halimifolia* is eastern USA are generally warmer than coastal Victoria. Whether or not Victorian saltmarshes are temperature-limiting for this species is not known, but if it is limited currently by low temperatures a spread further southwards may be possible.

4.1.4 Rainfall

Although projections for rainfall are less confident than are those for air temperatures (CSIRO-BOM 2015 a, b), it is expected that it will most likely decrease in south-eastern Australia with climate change. Changes in rainfall are not expected to be spread evenly across seasons or locations. Decreased rainfall will result in a decrease in runoff from the catchment, and this will be evident in a decrease in the median discharge of coastal rivers. Note too that an increase in extreme weather events may also see an increase in the incidence of severe flooding in these rivers.

Decreases in rainfall and freshwater runoff could have the following effects:

- Impacts on all aspects of the wetting and drying cycles of coastal wetlands, with longer periods between and reduced duration of freshwater inundation. A reduction in freshwater inundation over winter or spring could see impacts on the germination of saltmarsh plants, as well as on the successful recruitment and establishment of young plants.
- Exacerbate the development of hypersaline conditions, with possible conversion of intertidal saltmarsh to hypersaline flats.
- Replacement of areas of coastal wetlands currently vegetated with glycophytic (e.g. *Phragmites australis*) or brackish-water plants (e.g. *Melaleuca ericifoia*) by saltmarsh as a result of increased salinity.
- Change primary productivity and distributions of mangrove communities, probably towards increased vigour and a wider distribution.
- Modify patterns and rates of coastal sedimentation and erosion, with effects on the area suitable for mangrove or saltmarsh colonisation.

One of the most important impacts of changed rainfall patterns is its effect on wetland salinity regimes. Figure 17 shows a conceptual model developed to show the how altered patterns of rainfall and evaporation will combine to affect coastal wetlands. The effects are manifest through a range of pathways. Most interact with other elements of climate change, and this makes it impossible to develop models that deal with only climate change components in isolation or on a piece-by-piece approach. First, the combination of higher mean sea levels and increased storm surge activity will push the salt wedge in coastal rivers further upstream, resulting in saline intrusions into the lower, previously freshwater reaches. Second, this effect on the position of the tidal wedge will be exacerbated by decreased river discharge, which will weaken as a force that pushes the wedge towards the ocean. Small river discharge also means the salinity of the groundwater underlying coastal wetlands may increase. This, in turn, will be exacerbated by increases in evaporative losses. Both are likely to give rise to hypersaline conditions in the upper parts of coastal wetlands, areas that would formerly have been freshened by periodic rainfall or runoff from the nearby catchment. It should be clear how the processes operating in the conceptual models interact to generate a suite of complex interactions for coastal wetlands.

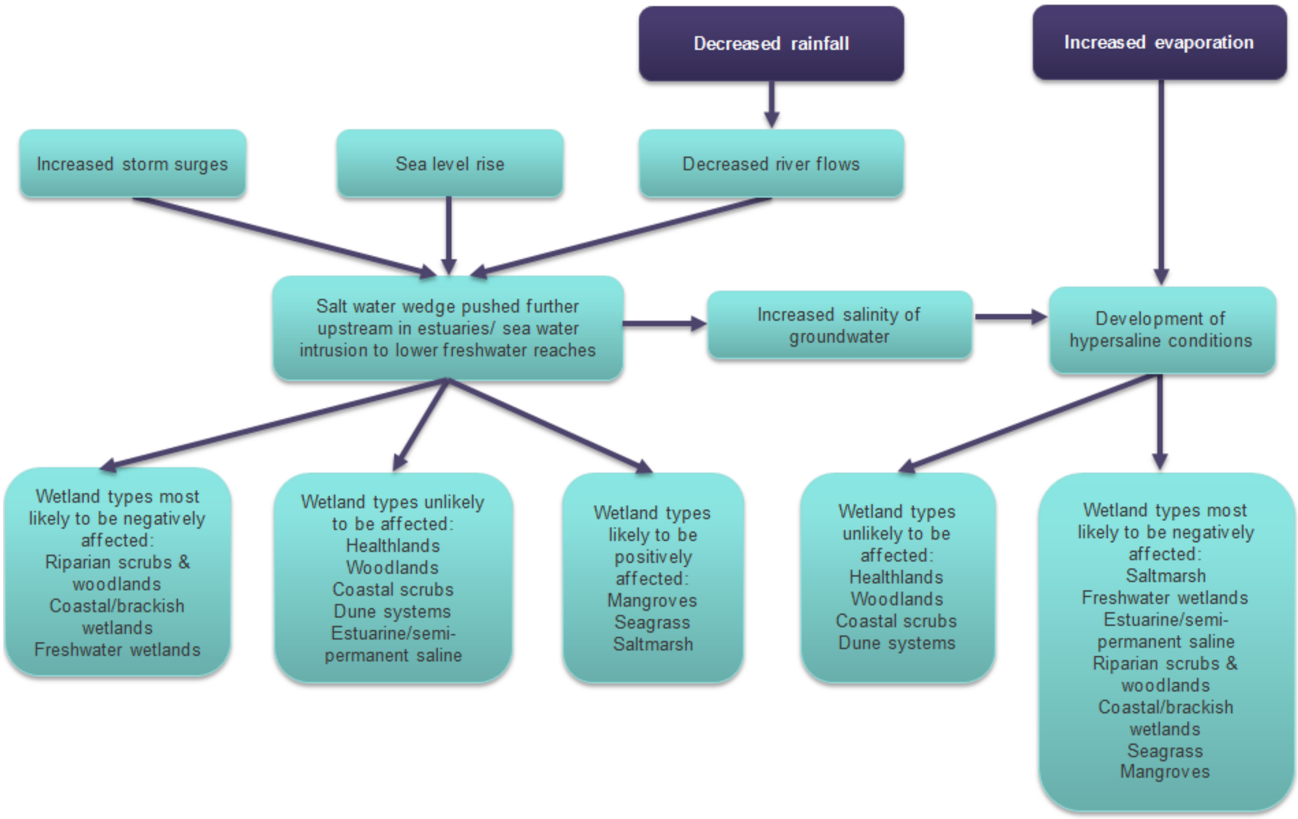


Figure 17: Conceptual model of the impact of altered patterns of rainfall and evaporation on coastal wetlands

Climate change is predicted to have major impacts on run-off from Victorian catchments and on river discharge (e.g. Timbal & Jones 2008) which is likely to impact on inundation and salinity regimes in coastal wetlands. The effects could be experienced either as a direct effect of decreased local run-off onto coastal wetlands (e.g. from the immediate hinterland) or as an indirect effect arising from altered base flows and patterns of over-bank flooding from rivers and streams during extreme events. In south-eastern USA, coastal saltmarsh has experienced widespread die-off over the past decade, and drought is thought to be one of the major causes of the losses. Drought not only led to reduced freshwater inflows, and thus the development of lethal hypersalinity in coastal environments, but allowed increased grazing pressure (by gastropods) to cause a cascade of ecological disruption that eventually resulted in large-scale losses of saltmarsh vegetation (Silliman *et al*. 2005).

Even at smaller scales, the vegetation of coastal wetlands is affected strongly by the amount and timing of freshwater inputs, though marine influences are often the most obvious of the hydrological inputs to estuarine wetlands (Boorman 2009). Hobday *et al*. (2006 c) noted the sensitivity of mangrove ecosystems to even slight changes to hydrological regimes, induced by either shifts in tidal inundation or fluxes of freshwater from the hinterland and nearby rivers. Shifts in freshwater penetration into coastal wetlands thus would be expected to have profound impacts on rates of primary productivity and perhaps even the on-going persistence of mangroves in some areas. For this reason, climate-related effects on freshwater run-off and stream discharge in southern Australia could have major ramifications for the structure and function of coastal wetlands.

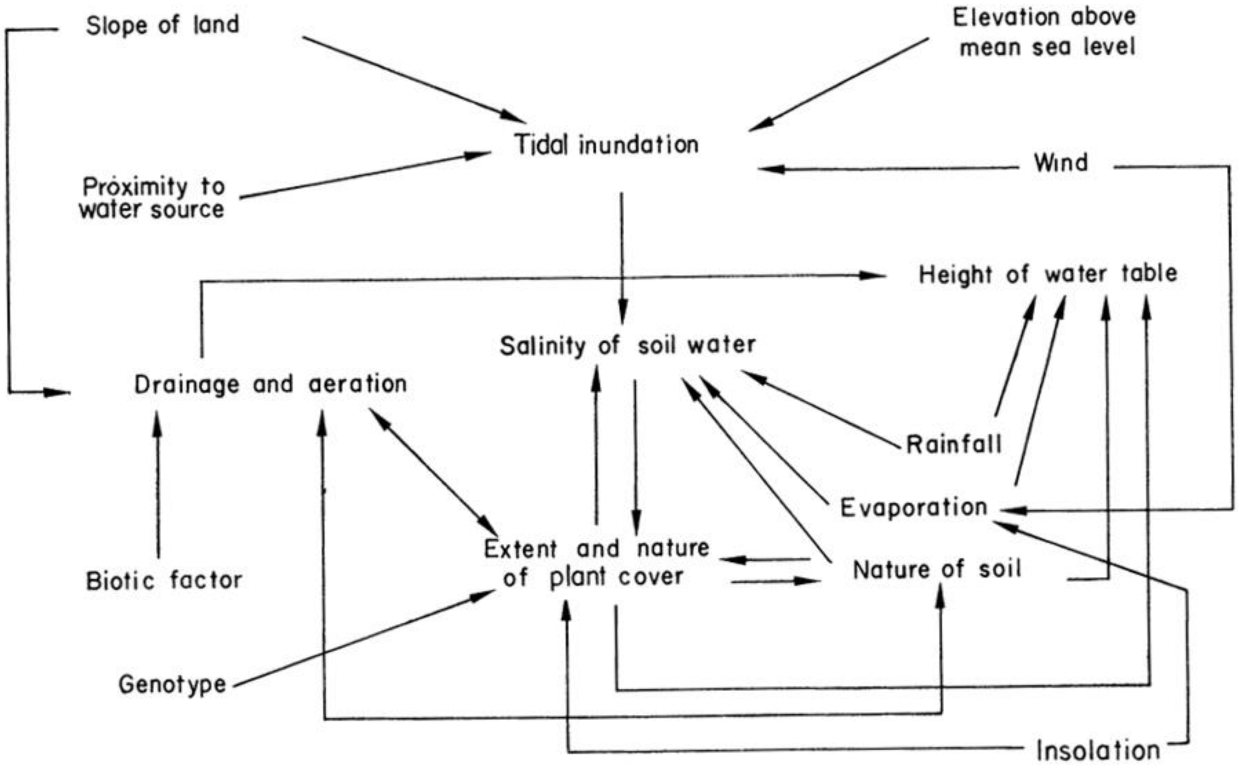


Figure18: Conceptual model of how diverse environmental factors interact with rainfall variations to influence salinity regimes in coastal wetlands (Clarke and Hannon 1969, Figure 1)

Figure 18 shows the conceptual understanding developed by Clarke and Hannon for mangroves and saltmarshes in the Sydney region in their pioneering paper of 1969. It shows how rainfall interacts with sea levels (reflected in 'tidal inundation'), local landscape features ('slope of land' and ' elevation above mean sea level') and groundwater ('height of the water table') to generate the variable salinity regimes that exist in coastal wetlands. This conceptual model likely holds for wetlands along the coast of Victoria as well. The interaction among a variety of environmental factors to generate variable inundation and salinity regimes is only one of many similar interactions that occur in coastal wetlands under the various drivers of climate change.

The significance of variations in groundwater levels is a topic often overlooked in assessments of the impacts of climate change on coastal wetlands. Fresh groundwater may be locally important in relieving coastal plant communities of high salinities. Adams & Bate (1999), showed how fresh groundwater partly explained the persistence of salt-intolerant Common Reed (*Phragmites australis*) in some South African estuaries where the overlying water was too salty for the plants to be expected to persist. The explanation requires plants be maintained by local inputs of fresh, shallow ground water such that even though the above-ground parts are exposed to a salty water column, the roots and rhizomes grow in a localised lens of freshwater. It has been proposed as one mechanism to account for the persistence of *Phragmites australis* in the saltiest parts of Gippsland Lakes, but extensive field assessments undertaken by Boon *et al*. (2015c) suggested it was not a viable explanation, as the shallow groundwater below all measured stands was no fresher than the overlying surface waters. Nevertheless, groundwater may play an important role in providing freshwater (and possibly nutrients) to coastal wetlands in other parts of the State, especially to the more upland coastal wetlands closer to any clear break of slope and thus to localised expressions of groundwater.

Figure 19 shows how a higher sea level can interact with groundwater extraction to change the height of the groundwater elevation and freshwater and saltwater interface in the coastal zone.

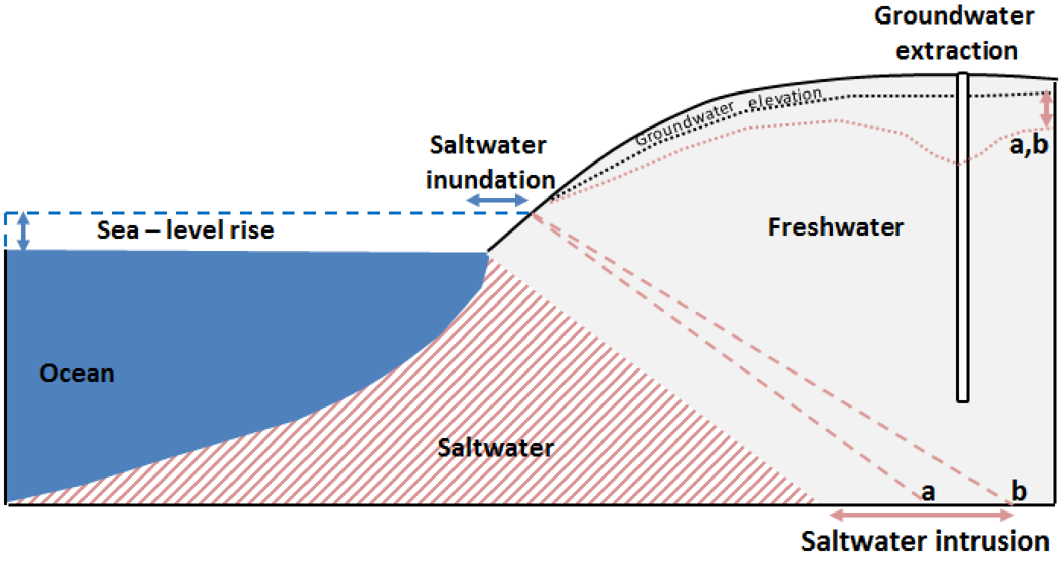


Figure19: Conceptual model of the cumulative impact of sea level rise (a) and groundwater extraction (b) on saltwater intrusion

4.2 Sensitivity ranking

The next step in sensitivity analysis was to characterise the impact of each climate change component as positive, negative and neutral for each wetland type based on the conceptual models presented in Section 4.1.

The conceptual models provide an analysis of the ecological consequences of climate change for wetland structure, function and wetland values, these were used to guide the sensitivity assessment. Table 12 provides a summary of the main ecological consequences for coastal wetlands of the four critical climate change components considered in this project.

Table 12: Ecological consequence of climate change components considered in this project

Climate change component	Climate change drive	Climate change impact	Ecological consequence of impact
Sea level	Increased eustatic sea level	Altered inundation and salinity regimes	Change to primary production and floristic compositions
		Seawater penetration into non-tidal areas	Change to primary production and floristic compositions
	Increased storm surge activity	Increased coastal erosion and shoreline recession	Physical loss of wetland habitat
		Seawater penetration into non-tidal areas	Change to primary production and floristic compositions
Carbon dioxide concentration	Increased atmospheric CO_2 concentration	Altered competitive relationship between C3 and C4 plants	Changes to floristic composition
	Acidification of water column	Carbonate dissolution	Loss of marine invertebrates
Rainfall	Lower average rainfall Changes in seasonal rainfall distributions More variable rainfall	Altered inundation and salinity regimes	Change to primary production and floristic compositions
		Altered sediment load	Creation or loss of potential wetland habitat
Temperature	Higher air temperatures	Wide range of phenological impacts	Changes to life histories

		Altered rates of primary production and decomposition	
	Higher water temperatures	Wide range of phenological impacts Altered rates of primary production and decomposition	Changes to life histories

Table 13 provides an assessment of the sensitivity of each wetland type identified in Section 2.3 to each climate change component presented in Table 12. The assessment of sensitivity is based on a ‘point in time and space’ approach that assesses how current wetland types are likely to respond to climate change components. The sensitivity assessment does not consider adaptive capacity; this component of the risk assessment is discussed in Section 4.3 and applied in Section 5.

At this point in time, limited information restricts the ability to quantify the ecological consequence of climate change. Therefore the assessment presented in Table 12 describes the overall direction of change, as follows:

- Positive (green): wetland type likely to have positive response to the climate change component
- Negative (red): wetland type likely to have negative response to the climate change component
- Neutral (yellow): wetland type unlikely to have any response to the climate change component

Table 13: Sensitivity (ecological response) of wetland type and associated EVC group to climate change components.

Wetland Type and corresponding EVC group		Climate change components and impacts on coastal wetlands								
		Increased Sea level and storm surges			**Increased carbon dioxide concentration**		**Decreased rainfall**		**Higher air temperature**	**Higher water temperature**
		Chronic salinisation	*Episodic salinisation*	*Erosion/ shoreline recession*	*Altered C3 and C4 relationship*	*Carbonate dissolution*	*Chronic salinisation*	*Altered sediment load*	*Phenological impacts/ altered primary productivity*	*Phenological impacts/ altered primary productivity*
Marine Embayment	Mangrove	Positive	Neutral to Negative	Negative	Positive	Neutral	Positive	Positive	Positive	Neutral
	Seagrass (not mapped)	Positive	Negative	Neutral	Neutral	Positive	Positive	Negative	Positive	Positive
	Saltmarsh	Positive	Negative	Negative	Negative	Neutral	Positive	Positive	Positive	Neutral
Estuarine - Intertidal	Mangrove	Positive	Neutral to Negative	Negative	Positive	Neutral	Positive	Positive	Positive	Neutral
	Saltmarsh	Positive	Negative	Negative	Negative	Neutral	Positive	Positive	Positive	Neutral
Estuarine - supratidal	Heathlands	Neutral	Neutral	Negative	Neutral	Neutral	Neutral	Neutral	Positive	Neutral
	Herb-rich woodlands	Neutral	Neutral	Negative	Neutral	Neutral	Neutral	Neutral	Positive	Neutral
	Coastal scrubs and woodlands	Neutral	Neutral	Negative	Neutral	Neutral	Neutral	Neutral	Positive	Neutral
	Wetland - estuarine/ semi-permanent saline	Neutral	Negative	Negative	Neutral	Neutral	Neutral	Positive	Positive	Neutral
Coastal floodplain	Riparian scrubs or swampy shrubs and woodlands	Negative	Negative	Negative	Neutral	Neutral	Negative	Positive	Positive	Neutral
	Coastal brackish wetlands	Negative	Negative	Negative	Neutral	Neutral	Negative	Positive	Positive	Neutral
	Freshwater wetlands	Negative	Negative	Negative	Neutral	Neutral	Negative	Positive	Positive	Neutral
Dune systems	Freshwater wetlands	Neutral	Neutral	Negative	Neutral	Neutral	Neutral	Neutral	Positive	Neutral

4.3 Adaptive capacity

There is considerable variation in the way systems are assumed to respond to perturbation[14] and still be considered 'resilient'[15] (Ludwig *et al*. 1997). Holling (1973) established a framework for determining resilience. It can mean at least seven different responses (Orians 1975), including:

- Constancy: lack of change in response to the perturbation
- Persistence: survival of a system or some portion of it in response to the perturbation
- Inertia: resistance to an external perturbation, similar to Holling's concept of 'resilience'
- Elasticity: the speed at which a system returns to its former state after the perturbation has passed
- Amplitude: the severity of perturbation required to modify a given system
- Cyclical: the property of a system to oscillate around a central point, despite external perturbations
- Trajectory: the property of a system to move towards a single end point despite differences in perturbations or their severity.

Adaptive capacity describes the ability of an ecosystem to adapt or adjust to environmental stressors, in this case as a result of the climate change, in the absence of management. Ecosystems with a high adaptive capacity are resilient to perturbation and can survive such perturbation with minimum loss of function. Ecosystems with low adaptive capacity are unable to resist such perturbations and the existing community may be replaced with species more able to cope (i.e. those that can adapt) the new conditions or in the worst case the system would not be able to support any communities (i.e. become bare ground).

For the types of coastal wetlands considered in this project, adaptive capacity is considered in the context of the exposure and the sensitivity (outlined in Section 1.2). Adaptive capacity is a combination of the sensitivity of a particular wetland type to the components of climate change and the degree of exposure (due to site specific characteristics), that may enhance or limit the wetland's ability to respond to climate change. It is also influenced by site-specific physical constraints (e.g. location of seawalls that hinder landward migration of mangrove or saltmarsh communities) and management actions (e.g. capacity to control saline intrusions by creating levees, or to provide freshwater from further upstream via the construction of a regulator) that can help achieve management objectives..

If a wetland type is very sensitive to a particular climate change component, then even if space is available for it to migrate into it might not be able to do so because of other limiting factors (e.g. rainfall, temperature, and water quality). This is particularly the case for biota and ecosystem processes that are sensitive to decreases in rainfall and/or increases in temperature and CO_2.These components of climate change are ubiquitous and thus even if space is available for migration these wetlands types will remain sensitive and may diminish across their entire range, due to competition from those species more suited to decreases in rainfall and/or increases in temperature and CO_2.

Similarly, a wetland may not be very sensitive to climate change components (or could react positively to climate change) and have capacity to move to a new location and so demonstrate high adaptive capacity. If, however, there is no suitable area for migration at a particular location, at the scale of that individual wetland it would have low adaptive capacity even though that particular wetland type may, in other locations or under different circumstances, be able to persist more broadly at the regional scale. A good example is provided by the existence of sea walls around many coastal wetlands in South Gippsland, which restrict the landward migration of affected wetlands to higher elevations.

The adaptive capacity of wetland types is summarised in Table 14. This assessment is based on the combination of sensitivity (Table 13) to climate change components and an understanding of adaptive mechanisms (from the conceptual models of likely wetland response to climate change presented in

[14]Perturbation is defined as a small change in a physical system, or more broadly any definable system https://en.wiktionary.org/wiki/perturbation

[15] Pimm, S L (1991) defines resilience as 'how fast a variable that has been displaced from equilibrium returns to it'.

Section 4.1). The table summarises the main adaptive mechanisms and the main factors limiting adaptation to climate change. This is based on limited information and therefore represents a 'best guess'. The table should be updated when further information becomes available.

Table14: Main adaptive capacity mechanisms of coastal wetland types to climate change components and the main limiting factor to adaptation

Wetland Type		Adaptive capacity[1]	Main adaptive mechanism	Main limiting factor
Marine Embayment / estuarine - intertidal	*Mangrove*	Adaptable	Sediment accretion, movement to higher elevations, positive response to increased temperature and increased atmospheric CO_2	Rate of sea-level rise; storm surge intensity and shoreline erosion; seawalls and other physical impediments
	Seagrass	Adaptable	Positive response to increased salinity	Storm surge intensity; smothering by catchment-derived sediments; reductions in underwater light fields consequent to catchment-associated processes
	Saltmarsh	Adaptable	Sediment accretion, movement to higher elevations, positive response to increased temperature (variable responses to increased CO_2)	Rate of sea-level rise; storm surge intensity and shoreline erosion; seawalls and other physical impediments; impacts of increased atmospheric CO_2 on floristic composition
Estuarine – supratidal	*Heathlands*	Unknown	Positive response to temperature, neutral to most other impacts until sea levels make the sites intertidal	Salinisation and waterlogging due to storm surge
	Herb-rich woodlands	Unknown	Positive response to temperature, neutral to most other impacts until sea levels make the sites intertidal	Salinisation and waterlogging due to storm surge
	Coastal scrubs and woodlands	Unknown	Positive response to temperature, neutral to most other impacts until sea levels make the sites intertidal	Salinisation and waterlogging due to storm surge
	Wetland - estuarine/ semi-permanent saline	Unknown	Positive response to temperature, neutral to most other impacts until sea levels make the sites intertidal	Salinisation and waterlogging due to storm surge
Coastal floodplain	*Riparian scrubs or swampy scrubs and woodlands*	Non-adaptable	Positive response to temperature	Salinisation and waterlogging (i.e., changes to wetting and drying regimes)
	Coastal brackish wetlands	Non-adaptable	Positive response to temperature	Salinisation and waterlogging (i.e., changes to wetting and drying regimes)
	Freshwater wetlands	Non-adaptable	Positive response to temperature	Salinisation
Dune systems	*Freshwater wetlands*	Unknown	Positive response to temperature, neutral to most other impacts	Physical loss of habitat; salinisation; possible changes to wetting and drying regimes

[1] where adaptive capacity is unknown, data gaps limit the ability to make clear assessment of adaptive capacity

4.4 Wetland values

Waterway management in Victoria is asset based; high value wetlands are those that support high environmental, social, cultural and/or economic values. These values, and the threats that may impact them, are set out in the Victorian Waterway Management Strategy (2013). In addition to these values coastal wetlands provide other services such as coastal protection, erosion control, and carbon sequestration.

Coastal wetlands in Victoria vary in the suite of values that they support (e.g. the presence of a particular threatened species, provision of specific recreational opportunities). Even within the same wetland type there may also be different values and priorities at different locations across the state. For example, some threatened species may only occur in one wetland type, but may not necessarily occur in every individual wetland of that type, and conversely some individual threatened species may be associated with several different wetland types.

Due to these differences, it difficult to assign value to individual coastal wetlands at a Statewide scale. However, the EVC approach to mapping coastal wetlands in Victoria (refer to Section 2.5) captures some information on wetland structure and function which can then be linked to wetland value and can be consistently applied across the State.

Wetland value is also considered at the site and regional scale in the DSF when considering management objectives and actions (Section 5), for example if it is known at a local scale that a wetland is important for a particular value (e.g. is a migratory shorebird site, supports threatened species) this will influence the objectives for that wetland and the approach to management.

5. Management options

If we exclude climate change mitigation as beyond the scope of Victorian wetland managers, their responses to climate change on wetlands in the coastal zone will inevitably focus on adaptation mechanisms. Three adaptation approaches are possible and are set out below.

1. The first approach is to resist change; in other words, to maintain the environmental *status quo*. This approach might be suitable for highly threatened species or very high value systems. The long-term preservation of threatened fauna species that require coastal saltmarsh (e.g. Orange-bellied Parrot *Neophema chrysogaster*) or particularly valuable wetland sites (e.g. some Ramsar sites) may require such a strategy. If climate change is to be resisted there are a limited number of interventions possible. For example, constructing sea walls to protect the hinterland, though the construction is expensive, the seawalls are prone to failure, and they inevitably alienate the land behind them. Moreover, sea walls will have to be added to in perpetuity as sea levels begin to rise. What this means is that sea walls can only ever be seen as a short term 'solution'. Boon *et al*. (2015d) discussed many of these in terms of future management of the Gippsland Lakes Ramsar site in the face of ongoing climate change.
2. The second approach is to promote resilience in coastal wetlands, at the level of the individual wetland and at the broader landscape scale. Gilman *et al.* (2008) called this approach a ''no regrets" reduction of stresses. Improving resilience is widely invoked as a mechanism for dealing with climate change (and for managing natural systems more generally) and could be applied to the case of coastal wetlands by maintaining habitat for wetland dependent species and ensuring that pest plant and animal species (e.g. *Spartina*) and other threats (e.g. uncontrolled grazing by stock) are adequately controlled.
3. The third adaptation approach is to enable wetlands to respond naturally to climate change. This would likely involve a process of 'managed retreat' that would allow coastal wetlands to migrate in response to rising sea levels, in this way mangroves would slowly move to higher elevations displacing saltmarsh and in turn saltmarsh would have to retreat further in to the hinterland. It is not clear if there is unalienated flat land behind the saltmarsh to allow for this migration and ultimately it may be that systems that are currently freshwater or brackish become more saline. Managed retreat would entail the facilitation of natural processes such as species dispersal and colonisation of new environments and assisted dispersal, and the creation of migration buffers (e.g. room to retreat) around individual wetlands. Rogers *et al*. (2016) have shown how managed retreat may be possible in some coastal wetland in south east Australia but is unlikely to be a viable option for many others.

The maintenance of ecological connectivity would also enable wetlands – and especially their motile biota – to respond better to the effects of climate change. In some cases active rehabilitation of degraded sites may be required to improve connectivity. The adequate representation of wetlands and refugia in a robust system of protected areas would also be a central component of any response based on 'managed retreat'. More controversially, the introduction of non-indigenous native taxa may be warranted, even if it does have an effect on local gene pools. If this option were invoked, novel ecosystems may be created. This would have to be carefully managed and implemented to avoid unintended outcomes (e.g. invasions by exotic weeds).

Many coastal wetlands are influenced by the impacts of threats not related to climate change such as urban development and nutrient enrichment from agricultural lands. These threats will interact in complex ways with the impacts of climate change. The outcomes from these interactions will be difficult to predict and will require careful monitoring and adaptive management strategies to minimise adverse impacts. The coastal ecosystems likely to be most at risk from climate change include estuaries and associated wetlands, coral reefs, constrained tidal flat communities and beaches where there is a lack of sediment replenishment (DoCC, 2009).

Management options can be developed at the individual wetland scale, the local landscape scale (e.g. as a mosaic of wetland types within a local area) or at a broader regional scale (e.g. with the aim of maintaining representative wetland types across a region).

The process for determining management options is an iterative one. It requires an understanding of the likely response of a wetland at a particular location, constraints to management, objectives for what a wetland manager wants to achieve (at the individual wetland, local and regional scale), and the management actions that could be implemented to achieve objectives.

The following sections provide advice on how to approach each of these management decisions.

5.1 Management constraints

Prior to determining management objectives it is necessary to identify and document constraints to management, these include, but are not limited to:

- **Barriers to migration.** This refers to the availability of space for wetlands to migrate landward as sea level rises. There are two main barriers to landward migration; topography and constructed linear barriers.
    - Topographic barriers to migration occur where there are steep slopes that limit space at a suitable elevation above sea level for wetlands to migrate to. As a result some wetlands will not have room to migrate landward or they may be able to migrate landward but in a more restricted space than they currently occupy. Again depending on elevation gradient, existing wetland zonation may be maintained in some locations but not others.
    - Constructed linear barriers are formed by elevated roads, levees, sea walls etc. In these situations suitable land may exist for landward migration but the presence of a road, or other constructed barrier, restricts migration. In some instances it may be possible to modify linear barriers to mititgate their impacts (e.g. through the installation of culverts under a road), in other instances mitigation may not be possible (e.g. where a sea wall or levee protects urban areas or high value land uses).
- **Land ownership and land use.** Privately owned land adjacent to coastal wetlands may represent a constraint to approaches such as managed retreat. Council planning schemes may be a good source of information to help identify land use zoning and hence help determine the extent to which this represents a constraint.
- **Funding availability.** Funding for management actions is likely to be limited and represents a constraint. Many actions aimed at improving wetland resilience and/or facilitating transition is likely to require significant funds.
- **Knowledge and data availability.** A lack of information represents a constraint to wetland management, for example to identify the wetland type, values supported by the wetland, undertake sensitivity analysis and to determine the expected response to climate change components.

The identification of management constraints will assist in the development of management objectives and actions by helping to identify what can and cannot be achieved in response to climate change components at a particular location.

5.2 Management objectives

Once potential constraints have been identified it is possible to develop management objectives at the individual wetland, local landscape and regional landscape scale.

5.2.1 Broad management objectives

As discussed above, the broad management objectives are:

- ***Save / maintain existing wetland type in current position*** - for example construction of levees/regulators on the seaward side to protect an existing location. This management objective may be applied to individual wetlands that support significant values that not present in other locations. However, this objective is likely to require significant resources to implement and require on-going management to operate and maintain infrastructure.

- ***Facilitate landward migration of existing wetland type*** **-** for example making space available in adjacent agricultural land for the wetland type to establish. This option maximises the ability to maintain existing wetland types within the broader landscape, but may have significant implication for existing land users and could also be costly to implement and manage.
- ***Facilitate transition to a new wetland type at the existing location*** **-** for example, existing saltmarsh or estuarine reedbeds becomes mangroves. Of all the 'actively managed' options, this option is the most straightforward to implement and is within the existing capability of wetland managers to achieve using the range of management actions currently available. Active management may be required to facilitate transition (e.g. weed control, revegetation),
- ***No intervention*** – for this objective the site is left to transition to a new state with no management assistance.

In developing management objectives at a specific site it is necessary have an understanding of wetland values and to consider local and regional objectives. Therefore, the development of objectives should be undertaken by wetland managers in consultation with relevant agencies and community stakeholders. It is important to consider the level of change for the site that is acceptable based on the values that it support. In some cases changes resulting from climate change components may be acceptable (e.g. low value site) and in other cases it may not be (e.g. high value site). Information on high value wetlands may be available in existing strategies such as the regional waterway strategies developed by catchment management authorities and the Healthy Waterway Strategy developed by Melbourne Water.

Consideration also needs to be given to maintaining a suite of different wetland types across the landscape. Wetlands of a given type may not be maintained at their existing locations, but may still be representated the local and regional scale.

When developing management objectives adjacent habitat types, wetland buffer zones, and transition zones between wetland and terrestrial habitats need to also be considered. For example, to facilitate landward migration it would be important to maintain or create linkages between wetland and terrestrial habitats.

Combinations of the management objectives listed above may also be identified across a range of time scales in response the degree of exposure of a wetland type to climate change. For example, for a wetland that has no landward migration opportunity but is likely to experience the impacts of sea level rise in the medium to long term (20 years) it may be appropriate to have the following management objectives:

- Sort term objective (next 10 to 15 years) - save / maintain existing wetland type in current position.
- Medium to long term objective (15 - 20 years) - facilitate transition to a new wetland type at the existing location.

This approach to setting management objectives is referred to as scenario planning and is discussed in more detail in Section 5.2.2.

As with any management approach, objective setting needs to be supported by appropriate monitoring of the ecosystem response to the management intervention, and adaptive management implemented as informed by the monitoring outcomes.

5.2.2 Adaptive management and other management approaches

Adaptive management is well established as a tool for managing natural systems (Allan and Stankey 2009). However, despite its prevalence as an approach for natural resource management, it is not clear that adaptive management is always the best or only way to address the management of complex natural systems. Figure 20 outlines a number of different management approaches, including adaptive management, and provides an indication of how appropriate they are for management according to relative uncertainty and controllability of natural systems.

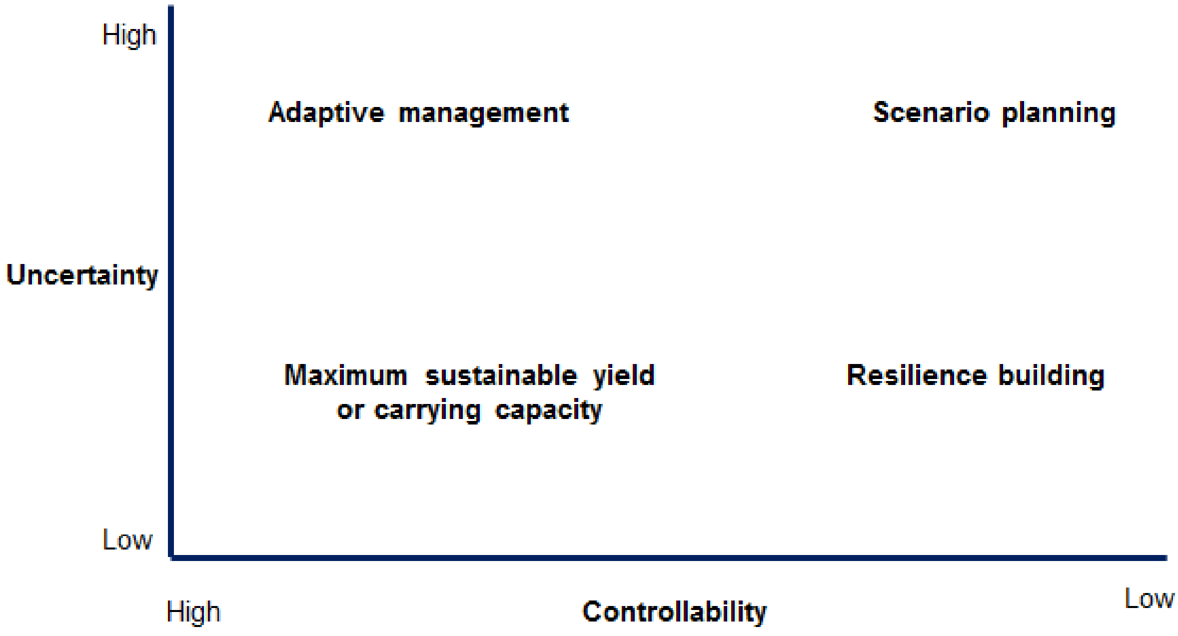


Figure 20: Appropriateness of different management approaches, including adaptive management, according to relative uncertainty and controllability of natural systems. Source: modified from Peterson (2005).

Peterson *et al*. (2003) and Peterson (2005) have argued that adaptive management applies best to situations that have high uncertainty but are, in principle, controllable. Adaptive management is centred on the idea that the system is manageable (e.g. interventions are possible), this makes it a controllable environment, however we are uncertain as to what the outcomes might be so we monitor the consequences of intervening throughout the adaptive management cycle. It is especially weak in systems subject to continuous or unrepeatable perturbations, where the responses are uncertain or where it may not be possible to intervene in controlled way.

In situations that are controllable and have low uncertainty, managing for maximum sustainable yield or maximum carrying capacity is the best option. The management of fisheries provides a good example of this, limits can be placed on the number of trawlers taking fish (i.e. the controllability is high) and the data on fish stocks is good which allows a clear relationship between the size of the fish stock and the number of trawlers taking fish to be determined (i.e. uncertainty is low).

In situations where there is less control, other options such as resilience building and scenario planning are perhaps more appropriate management approaches (see Figure 20). When the system is inherently uncontrollable but ecological outcomes are reasonably certain, resilience building may be the best approach to management. Resilience building involves the manipulation of a system to increase its ability to persist despite uncontrollable disturbance.

Where the system is both uncertain and uncontrollable, scenario planning is likely to be the most effective management tool. The Victorian Centre for Climate Change Adaptation Research (VCCCAR) has developed a guidebook to help practitioners use scenario based strategies to improved climate change adaptation decision making and planning[16]. A scenario in this approach is defined simply as a plausible future. Scenario planning considers all plausible future outcomes and is the best option when there is uncertainty in predicting which outcome will occur in the future. An example is the use of low, medium and high emission scenarios in climate change modelling where there is uncertainty around which route emissions will go down so projections are made for all three scenarios. The timing associated with scenario planning is informed by monitoring as it provides a warning to switch to a different scenario.

[16] http://www.vcccar.org.au/sites/default/files/publications/SPCA_GUIDEBOOK_FINAL_200711.pdf

What relevance has this to managing climate change components on coastal wetlands? In some situations there will be options for intervention and it may be possible to monitor the effectiveness of those interventions. The construction of sea walls to limit the intrusion of seawater into formerly fresh wetlands is an example, here adaptive management may be the best approach. But in other situations there may be low certainty as to outcomes and/or little or no opportunity to intervene so scenario planning or resilience building would be more appropriate. The response of different saltmarsh plant taxa to increasing concentrations of atmospheric CO_2 is an example. In this case there is no opportunity to intervene (it is not possible to control atmospheric CO_2 concentrations at the scale of a coastal wetland). Scenario planning or resilience building may be better management approaches; resilience building if there is reasonable certainty as to consequences, and scenario planning if there is not. Future projects might investigate these alternatives to the more commonly used adaptive management approach.

5.3 Management actions

Once management objectives have been identified it is then possible to identify suitable management actions for particular wetland types and climate change components.

5.3.1 Broad management actions

Table 16 summarises the broad management actions that are available to wetland managers to address particular climate change components for each wetland type, further detail is provided below. Table 17 shows how these management actions can be used to achieve the specific wetland objectives identified above. Monitoring is not considered a management action, but is critical for all approaches to inform adaptive management or scenario planning.

Specific actions within each of these broad management areas can then be developed at the individual wetland scale. There are guidelines available to assist in the development of specific management actions for implementation once the broad management actions are identified, for example:

- Peters, G., Morris, K., Frood, D., Papas, P. and Roberts, J. (2015). A Guide to managing livestock grazing in Victoria's wetlands. Decision framework and guidelines - Version 1.0, Arthur Rylah Institute for Environmental Research Technical Report Series, Report number 265
- Morris, K. and Papas, P. (2012), Wetland conceptual models: associations between wetland values, threats and management interventions, Version one, Arthur Rylah Institute for Environmental Research Technical Report Series, Report number 237.
- DELWP wetland buffers guidelines (in prep.)
- DELWP wetland revegetation guidelines (in prep.)
- DELWP wetland invasive species management guidelines (in prep.)
- SKM (2005). Guidelines for the design and operation of environmentally friendly wetland regulators (MDBC project report R2002). Report by Sinclair Knight Merz for the MDBC.

Land use on private land

Where the land available for coastal wetlands to migrate landward is privately owned influencing the way the land is managed may be an important component of managing for climate change.

This approach could be facilitated through incentive schemes such as Wetland Tender[17] and the Trust for Nature Stewardship Program. These programs are used to support landholders to manage their land for conservation purposes using incentive payments and include the preparation of a management plan.

[17] Wetland Tender Field Officer Manual can be found at http://www.depi.vic.gov.au/water/rivers-estuaries-and-wetlands/wetlands/managing-wetlands

Land acquisition/planning

Private land could be purchased for coastal wetlands to migrate landward. The private land is acquired for new conservation reserves, in this case coastal wetlands, and managed by an appropriate public land manager in accordance with a management plan that applies to the area.

New infrastructure on seaward side of wetland

For wetlands with significant values, where the objective of maintaining the existing wetland in its current location has broad support, infrastructure could be used to prevent increased levels of inundation. This could include levees and/or regulating structures to control the inflow and outflow of water, sized to prevent inundation under various sea level rise scenarios. Consideration needs to be given to the cost and long term viability of this approach. Sea level rise may also cause a rise in, and increased salinity of, groundwater regardless of whether sea water is excluded. This approach may provide a short term solution to maintain values at existing locations while new wetlands establish that will support those values.

Infrastructure removal/ modification on landward side of wetland

It may be possible to modify or remove existing infrastructure (e.g. raised roads, levees) that prevents landward migration of wetlands. Modification may be as simple as installation of culverts to allow unrestricted flow of water, seeds, propagules and animals into new areas. In some areas, realignment/relocation of roads and levees may be required to allow landward migration. This also has the advantage of moving infrastructure out of areas likely to experience increased inundation.

Invasive species control

It is often assumed saline coastal wetlands experience environmental conditions so severe that they are largely immune to invasion by exotic plant species. In fact, these types of wetlands are often highly susceptible to invasions by exotic plants. Site-based studies of coastal saline wetlands in south-eastern Australia have confirmed that exotic taxa are often a common element of the flora. Clarke (1993), for example, recorded a vascular flora of 140 taxa in the mangrove, saltmarsh and peripheral vegetation of the relatively isolated and unmodified Jervis Bay (New South Wales), of which 15 taxa were introduced. A recent assessment of Victorian mangroves and coastal saltmarsh indicated that exotic plants were the third most pervasive threat, after land 'reclamation' and grazing (Boon *et al*. 2015a). Carr (2012) identified an exotic flora of 121 taxa, of which 119 occurred in the upper (dry) saltmarsh zone and two in the lower (wet) zone or in mangroves. Two weeds of the mangrove zone in south-eastern Australia − the cordgrasses *Spartina anglica* and *Spartina* x *townsendii* (Nightingale and Weiller 2005) − are serious invaders of saline coastal wetlands. The 119 exotic taxa identified by Carr (2012) have highly diverse life forms. Boon (2015a) identified the twenty most serious exotic plant species in Victorian coastal saltmarsh, the most problematic of which were Cock's Foot **Dactylis glomerata*, Tall Fescue **Festuca arundinacea*, Sea Barley-grass **Hordeum marinum*, Spiny Rush **Juncus acutus* ssp. *acutus*, Wimmera Rye-grass **Lolium rigidum*, Tall Wheat Grass **Lophopyrum ponticum* (syn. *Agropyron elongatum*, *Elymus elongatus*, *Elymus obtusiflorus*, *Thinopyrum ponticum*), Coast Barb-grass **Parapholis incurva*, Slender Barb-grass **Parapholis strigosa*, Toowoomba Canary Grass **Phalaris aquatica*, and Buck’s-horn Plantain **Plantago coronopus*. The presence of exotic taxa, especially weeds in coastal wetlands is one mechanism by which their resilience to climate change might be decreased. Weed control, therefore is likely to be an important factor in managing coastal wetlands in the face of ongoing climate change.

Active revegetation

In addition to weed control, active revegetation may be required to assist in wetland transition and migration. Revegetation could be used to assist in the establishment of species that may have low dispersal ability or poor recruitment success, or to create interim communities while new wetlands communities establish. A number of new guidelines are being developed to assist managers in the establishment of wetlands buffers and wetland revegetation activities (https://www.water.vic.gov.au/waterways-and-catchments/rivers-estuaries-and-waterways/wetlands/managing-wetlands).

Groundwater and surface water regulation

Surface water and groundwater supply and quality are likely to be affected by higher temperatures, increased evaporation rates, changes in amount and patterns of rainfall and sea level rise (Commonwealth of Australia 2013). This reduction in water availability will put pressure on Victoria's surface water and groundwater resources and wetland systems. Groundwater and surface water regulation is not considered as a management action for climate change adaptation at an individual wetland scale, however consideration of the likely impacts on nearby high value wetlands should be taken in to consideration when managing any increased extraction of either surface water or groundwater resources.

Education and community engagement

Education, engagement and communication programs are important in helping the community to understand and play an active role in finding solutions to potential biodiversity loss as a result of climate change (Commonwealth of Australia 2013). Public understanding of the impacts of climate change on biodiversity is often quite low, however it is important for the development and success of climate change management and adaptation programs.

For the success of climate change management and adaptation, the community needs to understand the impacts of climate change on the coastal environment. Linking these changes to the communities' activities and values, and establishing constructive actions that may be able to manage the changes through consultation with the community are important components community education and engagement.

Fire management

Wildfires have been reported in mangroves, coastal saltmarsh and in brackish-water paperbark swamps (Boon *et al*. 2011). Fire impacts will likely increase as the climate warms and dries, as wetlands desiccate and as the vegetation dries out. Fire may be used as a control measure for some weeds of coastal wetlands, but considerable thought would have to be given to this before it were implemented at a given site because of the risks of escaped burns and other unintended consequences (e.g. reduction in water quality).

Blue carbon

Coastal wetlands store a significant amount of carbon[18]. Managed properly, seagrasses, mangroves and coastal salt marshes and other types of coastal wetland could play an important role in the mitigation of atmospheric climate forcing (Duarte *et a*l. 2013). At present, however, the widespread conversion of coastal wetlands to other uses (e.g. aquaculture) contributes up to 19% of all emissions from deforestation globally (Pendleton *et al*. 2012). These contributions are not accounted in any current regulatory or market mechanism. Nor are these losses fully acknowledged in terms of the other ecosystem services foregone when coastal wetlands are cleared for agriculture or for aquaculture. Although an important mitigation action for reducing carbon emissions, blue carbon is not considered as a management action at an individual wetland scale for application in the DST.

[18] www.bluecarbonlab.org

Table 16: Broad management actions suitable for addressing specific climate change components

Management Action	Sea level		Carbon Dioxide concentration		Rainfall			Temperature	
	Increased eustatic sea levels	Increased storm surge activity	Increased atmospheric CO_2 concentration	Acidification of water column	Lower average rainfall	Changes in seasonal rainfall distribution	More variable rainfall	Higher air temperature	Higher water temperature
Influence private land management	✓	✓			✓	✓	✓		
Land acquisition/ planning	✓	✓			✓	✓	✓		
New infrastructure on seaward side of wetland	✓	✓			✓	✓	✓		✓
Infrastructure removal/ modification on landward side of wetland	✓	✓							
Invasive species control			✓	✓	✓	✓	✓	✓	✓
Active revegetation	✓	✓	✓	✓	✓	✓	✓	✓	✓
Education and community engagement	✓	✓	✓	✓	✓	✓	✓	✓	✓
Fire Management					✓	✓		✓	

Table 17: How management actions relate to various management objectives

Management Actions	Broad management objectives			
	Save/ maintain existing wetland in current position	Facilitate landward migration of existing wetland type	Facilitate transition to new wetland type in current location	No intervention
Influence private land management	✓	✓	✓	
Land acquisition/ planning		✓		
Active revegetation	✓	✓	✓	
Invasive species control	✓	✓	✓	
New infrastructure on seaward side of wetland	✓			
Infrastructure removal/ modification on landward side of wetland		✓		
Education and community engagement	✓	✓	✓	
Fire Management	✓			

5.3.2 Timing and sequencing of management actions

When identifying suitable management actions for particular wetland types and climate change components, the timing and sequencing of these actions should also be identified. The drivers of climate change components will alter over time and therefore so should the management actions. Currently the main driver of climate change is a drying climate (resulting from increased temperature and reduced rainfall) with sea level rise not being the overwhelming threat, therefore in the next 10 to 20 years management should focus on responding to the drier climate. When sea level rise becomes the major threat, likely in 20 to 30 years, this would then become the focus for management and therefore actions should be adjusted to reflect this. Table 18 provides an example of the timing and sequencing of management actions, where the dotted line represents the planning phase and the solid line the implementation phase.

Table 18: Timing and sequencing of management actions

6. Conclusions and recommendations

The detailed technical information provided in this report (Volume Two) supports the application of the DSF (see Volume One) and describes the logic and assumptions behind each of the considerations underpinning it. Wetland managers can use this technical information to determine the exposure, sensitivity and adaptive capacity of different types of coastal wetlands to climate change components and select appropriate management objectives and actions.

At this point in time, limited information restricts the ability to quantify the ecological consequences (including the sensitivity and adaptive capacity of wetland types) of climate change beyond a generalised approach. It is therefore recommended that further research be undertaken into the specific ecological consequences of climate change.

The successful management of climate change impacts on coastal wetlands not only requires the involvement of wetland managers and the community, but also requires State policies and procedures to be put in place that allow for long term management and planning. It is recommended that further investigation and consultation with wetland managers be undertaken to identify and resolve any issues and complexities associated with statewide issues that may constrain long term management (e.g. how to manage the impacts of climate change on crown land inundation and boundaries).

7. References

Adam P (2008). Likely impacts of climate change on coastal marshes and floodplains. In *Climate change, sea level rise and wetland adaptations*. Workshop notes. Sydney Olympic Park, 5-6 June 2008.

Adams JB and Bate GC (1999). Growth and photosynthetic performance of *Phragmites australis* in estuarine waters: a field and experimental evaluation. *Aquatic Botany* 64: 359−367.

Allan C and Stankey GH (2009). *Adaptive management. A practitioner's guide*. CSIRO, Collingwood & Springer, Dordrecht.

Aquatic Ecosystems Task Group (2012). *Aquatic ecosystems toolkit. Module 2. Interim Australian national aquatic ecosystem classification framework*. Australian Government Department of Sustainability, Environment, Water, Population and Communities, Canberra.

Ashton DH (1971). Mangroves in Victoria – point of view. *Victoria's Resources* 13: 27-30.

Ball D, Blake S and Plummer A (2006). Review of marine habitat classification systems. Parks Victoria Technical Series 26.Parks Victoria, Melbourne.

Barbier EB, Hacker SD, Kennedy C, Koch EW, Stier AC & Silliman BR (2011). The value of estuarine and coastal ecosystem services. *Ecological Monographs* 81:169-93.

Barson MM and Calder DM (1981). The vegetation of the Victorian coast. *Proceedings of the Royal Society of Victoria* 92: 55-65.

Bateman IJ, Abson D, Beaumont N, Darnell A, Fezzi C, Hanleys N, *et al*. (2011). Economic values from ecosystems. Chapter 22. In *The UK National Ecosystem Assessment Technical Report*. United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC), Cambridge UK.

Bird ECF and Barson MM (1975). Shoreline changes in Westernport. *Proceedings of the Royal Society of Victoria* 87: 15-28.

Bird ECF (1993). *The coast of Victoria: the shaping of scenery*. Melbourne University Press, Carlton.

Bird ECF (2006). The effects of higher sea levels on the coasts of Port Phillip Bay. *The Victorian Naturalist* 123: 49-53.

Bird ECF (2008). *Coastal geomorphology: An introduction*. 2nd edition. Wiley, Chichester.

BMT-WBM (2007). *Ramsar snapshot study – final report*. Report to Department of the Environment and Water Resources, Canberra.

Bonan GB (2002). *Ecological climatology. Concepts and applications*. Cambridge University Press, Cambridge.

Boon PI, White M & Sinclair S (2010). Climate change impacts on Victoria's coastal vegetation (mangroves and saltmarsh): Western Port case study. *Institution of Engineers Australia: Practical responses to climate change 2010 conference*. Melbourne, 29 September to 1 October 2010. (Full refereed paper: Paper 107: Presentation 107)

Boon PI *et al*. (2011). *Mangroves and coastal saltmarsh of Victoria: distribution, condition, threats and management*. Report to DSE, Bendigo. 513 pp. Available on-line at www.ozcoasts.gov.au/geom_geol/vic/index.jsp

Boon PI (2012). Coastal wetlands of temperate eastern Australia: will Cinderella ever go to the ball? *Marine and Freshwater Research* 63: 845-855.

Boon PI, Allen T, Carr G, Frood D, Harty C, McMahon A, Mathews S, Rosengren N, Sinclair S, White M & Yugovic J (2015a). Coastal wetlands of Victoria, south-eastern Australia: providing the inventory and condition information needed for their effective management and conservation. *Aquatic Conservation: Marine and Freshwater Ecosystems* 25: 454-479.

Boon PI, Rosengren N, Frood D, Oates A & Reside J (2015b). *Shoreline geomorphology and fringing vegetation of the Gippsland Lakes. Volume 1: A literature review*. Report to Gippsland Lakes Ministerial Advisory Committee.

Boon PI, Rosengren N, Frood D, Oates A & Reside J (2015c). *Shoreline geomorphology and fringing vegetation of the Gippsland Lakes. Volume 2: Field & laboratory assessments*. Report to Gippsland Lakes Ministerial Advisory Committee.

Boon PI, Cook P & Woodland R (2015d). The challenges posed by chronic environmental change in the Gippsland Lakes Ramsar site. *Marine and Freshwater Research* http://dx.doi.org/10.1071/MF14222

Boon PI, Keith D & Raulings E (2016). Vegetation of coastal floodplains and wetlands. In *Vegetation of Australia's riverine landscapes: biology, ecology and management*. Edited by Capon S, James C & Reid M. Pages 145-176. CSIRO Publishing, Clayton.

Boorman LA (2009). The role of freshwater flows on salt marsh growth and development. In *Perillo, G.M.E. et al*. (Ed.) (2009). *Coastal wetlands: an integrated ecosystem approach*. pp. 493-514

Borja A (2005). The European water framework directive: A challenge for nearshore, coastal and continental shelf research. *Continental Shelf Research 25*: 1768–1783

Bulthius DA (1983). Effects of in situ light reduction on density and growth of the seagrass *Heterzostera tasmanica* (Martens ex Aschers) den Hartog in Western Port, Victoria, Australia. *Journal of Marine Experimental Biology and Ecology* 67: 91–103.

Burley JG, McAllister RRJ, Collins KA and Lovelock CE (2012). Integration, synthesis and climate change adaptation: a narrative based on coastal wetlands at the regional scale. *Regional Environmental Change* 12: 581-593.

Burroughs WJ (2005). *Climate change in prehistory: the end of chaos*. Cambridge University Press, Cambridge.

Burroughs WJ (2007). *Climate change: a multidisciplinary approach*. 2nd edition. Cambridge University Press, Cambridge.

Cahoon DR (2006). A review of major storm impacts on coastal wetland elevations. *Estuaries and Coasts* 29: 889-898.

Carr GW (2012). Inventory of Victorian marine, estuarine and saltmarsh vascular plant species. In *'Estuary plants and what's happening to them in south-east Australia*.' (Eds G Sainty, J Hosking, G Carr, P Adam) pp. 398−421. (Sainty and Associates: Potts Point)

Carter RWG (2013). *Coastal environments: an introduction to the physical, ecological, and cultural systems of coastline*s. Elsevier, Amsterdam.

Clarke LD and Hannon NJ (1969). The mangrove swamp and salt marsh communities of the Sydney district: II. The holocoenotic complex with particular reference to physiography. *Journal of Ecology*, 57: 213-234.

Clarke PJ (1993) Mangrove, saltmarsh and peripheral vegetation of Jervis Bay. *Cunninghamia* 3, 231−253.

Commonwealth of Australia 2013. *Managing Australia's biodiversity in a changing climate: the way forward*. Final report of the inquiry into Australia's biodiversity in a changing climate. House of Representatives Standing Committee on Climate Change, Environment and the Arts.

Connolly R (2012). *Marine climate change: impacts & adaptation report card 2012*. Seagrasses. http://www.oceanclimatechange.org.au/content/index.php/2012/report_card_extended/category/seagrass

Costanza R, de Groot R, Sutton P, van der Ploeg S, Anderson SJ, Kubiszewski I, *et al*. (2014). Changes in the global value of ecosystem services. *Global Environmental Change* 26:152-8.

Cowardin LM, Carter V, Golet F & LaRoe ET (1979). Classification of wetlands and deepwater habitats of the United States. *Fish and Wildlife Service.* Report OBS-79/31.

Cowardin LM & Golet FC (1995). US Fish and Wildlife Service 1979 wetland classification: a review. *Vegetation* 118: 139-152.

Creighton C, Boon PI, Sheaves M & Brookes J (2015). Revitalising Australia's estuaries – what benefits at what cost? *Marine and Freshwater Research* 66: 493-507.

Crowell M, Edelman S, Coulton F, McAfee S (2007). How many people live in coastal areas? *Journal of Coastal Research* 23: iii-iv.

CSIRO and BOM (2015a). *Southern slopes cluster report. Climate change in Australia projections for Australia's natural resource management regions. Full Report*. CSIRO and Bureau of Meteorology, Canberra. Available on-line at http://www.climatechangeinaustralia.gov.au/en/impacts-and-adaptation/nrm-regions/

CSIRO and BOM (2015b). *Climate change in Australia. Projections for Australia's NRM regions. Southern slopes. Summary report.* CSIRO and Bureau of Meteorology, Canberra. Available on-line at http://www.climatechangeinaustralia.gov.au/en/impacts-and-adaptation/nrm-regions/

CSIRO and BOM (2015c). *Climate Change in Australia Information for Australia's Natural Resource Management Regions: Technical Report.* CSIRO and Bureau of Meteorology, Australia. Available on-line at http://www.climatechangeinaustralia.gov.au

Department of Climate Change (DoCC) (2009). *Climate Change Risks to Australia's Coast – A First Pass National Assessment*. Published by Commonwealth of Australia, Department of Climate Change.

Department of Conservation, Forests and Lands (1988). *Wetlands conservation program for Victoria*. State Government of Victoria, Melbourne.

Department of Environment and Primary Industries (2013a). Statewide wetland geospatial inventory update. Report prepared for the Department of Environment and Primary Industries (now DELWP) by Alluvium Consulting Pty Ltd

Department of Environment and Primary Industries (2013b). *Benchmarks for wetland ecological vegetation classes in Victoria*. Department of Environment and Primary Industries, East Melbourne, Victoria

Department of Environment, Land, Water and Planning (2015). *Wetland/ Estuary dependent EVCs*. Department of Environment, Land, Water and Planning, East Melbourne, Victoria.

Department of Sustainability and Environment (2009). *A field guide to Victorian wetland ecological classes for the index of wetland condition*. State Government of Victoria, Melbourne.

Department of Environment, Land, Water and Planning (2014). *The Victorian wetland classification framework* 2014.Department of Environment, Land, Water and Planning, East Melbourne, Victoria.

Duarte CM, Losada IJ, Hendriks IE Mazarrasa I, Marba N (2013). The role of coastal plant communities for climate change mitigation and adaptation. *Nature Climate Change* 3: 961-8.

Duke N (2006). *Australia's mangroves. The authoritative guide to Australia's mangrove plants*. University of Queensland Press, St Lucia.

East Gippsland Catchment Management Authority (CMA), 2015. *East Gippsland regional catchment strategy: Climate change adaptation and mitigation plan*

Environment Australia (2001). *A directory of important wetlands in Australia*. 3rd Edition. Environment Australia, Canberra.

Eslami-Andargoli L, Dale P, Sipe N & Chaseling J (2010). Local and landscape effects of spatial patterns of mangrove forest during wetter and drier periods: Moreton Bay, southeast Queensland, Australia. *Estuarine, Coastal and Shelf Science* 89: 53-61.

FAO (2012). *Coastal GTOS: Strategic design and phase 1 implementation plan*. FAO, Rome.

Finlayson CM, Davis JA, Gell PA, Kingsford RT and Parton KA (2013). The status of wetlands and the predicted effects of climate global climate change: the situation in Australia. *Aquatic Sciences* 75: 73-93.

Finlayson CM, Mitchell DS (1999). Australian wetlands: the monitoring challenge. *Wetlands Ecology and Management 7*, 105−112.

Freiss DA, Krauss KW, Horstman EM, Balke T, Bouma TJ, Galli D and Webb EL (2012). Are all intertidal wetlands naturally created equal? Bottlenecks, thresholds and knowledge gaps to mangrove and saltmarsh ecosystems. *Biological Reviews* 87: 346-366.

Frood D (2012). *Water and salinity regime and depth preferences for Victorian wetland ecological vegetation classes*. Report to DSE.

Frood D, Boon PI, Oates A, Reside J and Maxwell R (2015). *Benchmarking wetland flora in the Lower Latrobe wetlands*. Report to West Gippsland CMA.

Garnaut R. (2011). *The Garnaut Review 2011 – Australia in the global response to climate change*. Report to the Commonwealth of Australia.

Gilman E, Ellison J & Coleman R (2007). Assessment of mangrove response to projected relative sea-level rise and recent historical reconstruction of shoreline position. *Environmental Monitoring and Assessment* 124: 105-130.

Gilman EL, Ellison J, Duke NC & Field C (2008). Threats to mangroves from climate change and adaptation options: a review. *Aquatic Botany* 89: 237-250.

Gitay H, Finlayson CM and Davidson N (2011). *A framework for assessing the vulnerability of wetlands to climate change*. Ramsar Convention Secretariat, Gland.

Gray AJ & Mogg RJ (2001). Climate impacts on pioneer saltmarsh plants. *Climate Research* 18: 105-112.

Hobday AJ, Okey TA, Poloczanska ES, Kunz TL & Richardson AJ (2006). *Impacts of climate change on Australian marine life. Part C: Literature review*. Australian Greenhouse Office, Canberra.

Hobday AJ and Lough JM (2011). Projected climate change in Australian marine and freshwater environments. *Marine and Freshwater Research* 62: 1000–1014

Holling CS (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4: 1-23.

Howard-Williams C (1985). Cycling and retention of nitrogen and phosphorus in wetlands: a theoretical and applied perspective. *Freshwater Biology* 15: 391-431.

IPCC (2014a). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132 pp.

IPCC (2014b): *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 688.

Jevrejeva S, Grinsted A & Moore JC (2014). Upper limit for sea level projections by 2100. *Environmental Research Letters* 9: 104008.

Johnson D (2009). *The geology of Australia*. 2nd edition. Cambridge University Press, Port Melbourne.

Johnston EM, Hedge LH and Mayer-Pinto M (2015). The urgent need to understand port and harbour ecosystems. *Marine and Freshwater Research* 66: i-ii.

Kay R and Alder J (1998). *Coastal planning and management*. CRC Press, Boca Raton.

Laegdsgaard P (2006). Ecology, disturbance and restoration of coastal saltmarsh in Australia: a review. *Wetlands Ecology and Management* 14: 379-399.

Kirkman H and Boon PI (2012). *Review of mangrove planting activities in Western Port 2004-2011*. Report to Western Port Seagrass Partnership.

Lazarow N, Fearon R, Souter R & Dovers S (2006). *Coastal management in Australia: Key institutional and governance issues for coastal natural resource management and planning*. CRC for Coastal Zone, Estuary and Waterway Management, Gold Coast.

Loebl M, van Beuskon JEE & Reise K (2006). Is spread of the neophyte *Spartina anglica* recently enhanced by increasing temperatures? *Aquatic Ecology* 40: 315-324.

Lough JM and Hobday AJ (2011). Observed climate change in Australian marine and freshwater environments. *Marine and Freshwater Research*, 62: 984–999.

Lovelock CA, Skilleter G and Saintilan N (no date). *Marine climate change impacts and adaptation report card. Mangroves and tidal wetlands*. http://www.oceanclimatechange.org.au/content/images/uploads/Mangroves_and_tidal_wetlands_final.pdf

Ludwig D, Walker B & Holling CS (1997). Sustainability, stability, and resilience. *Ecology and Society* 1: Article 7.

McInnes KL, Abbs DJ & Bathols JA (2005 a). *Climate change in eastern Victoria. Stage 1 report: the effect of climate change on coastal wind and weather patterns*. Report to Gippsland Coastal Board. CSIRO, Aspendale.

McInnes KL, Macadam I, Hubbert GD, Abbs DJ & Bathols J (2005 b). *Climate change in eastern Victoria. Stage 2 report: the effect on storm surges*. Report to Gippsland Coastal Board. CSIRO, Aspendale.

McInnes KL, Macadam I & Hubbert GD (2005 c). *Climate change in eastern Victoria. Stage 2 report: the effect of climate change on extreme sea levels in Corner Inlet and the Gippsland Lakes*. Report to Gippsland Coastal Board by CSIRO, Aspendale.

Mitsch WJ & Gosselink JG (1993). *Wetlands*. 2nd Edition. Van Nostrand, New York.

Morris JT, Sundareshwar PV, Nietch CT, Kjerfe B & Cahoon DR (2002). Responses of coastal wetlands to rising sea levels. *Ecology* 83: 2869-2877.

Morris L (2013). Chapter 2. Implications of future climate change for seagrass and soft sediments. In *Implications of future climate change for Victorian's marine environments*. Eds Klemke J & Arundel H. Report to Glenelg Hopkins CMA.

Morrisey DJ, Swales A, Dittmann S, Morrison MA, Lovelock CE & Beard CM (2010). The ecology and management of temperate mangroves. *Oceanography and Marine Biology: An Annual Review* 48: 43-160.

Morton RM (1990). Community structure, density and standing crop of fishes in a subtropical Australian mangrove area*. Marine Biology* 105: 385-94.

National Resource Management Ministerial Council (2006). *National cooperative approach to integrated coastal zone management.* Canberra.

Nehring S & Hesse K-J (2008). Invasive alien plants in marine protected areas: the *Spartina anglica* affair in the European Wadden Sea. *Biological Invasions* 10: 937-950.

Nelson WA (2009). Calcified macroalgae – critical to coastal ecosystems and vulnerable to change: a review. *Marine and Freshwater Research* 60: 787-801.

Nicholls RJ and Small C (2002). Improved estimates of coastal population and exposure to hazards released. *Eos* 83: 302-305.

Nielsen, D. and M. Brock. 2009. Modified water regime and salinity as a consequence of climate change: prospects for wetlands of Southern Australia. *Climatic Change* 95:523-533.

Nightingale ME, Weiller CM (2005) Spartina. *In Flora of Australia. Volume 44B. Poaceae 3*. Edited by K Mallet. pp. 310−311. Department of the Environment and Heritage, Canberra

Nott J & Hubbert G (2003). Inundation levels and coastal impacts from two high intensity tropical cyclones in Western Australia. *Proceedings of the Tropical Cyclone Coastal Impacts Program Workshop*. Canberra, 9 September 2003 (original not seen; cited from Walsh 2004).

Oliver J (1982*). The geographic and environmental aspects of mangrove communities: climate. In Mangrove ecosystems in Australia. Structure, function and management*. Edited by Clough BF. Pages 19-30. Australian Institute of Marine Science, Townsville & Australian National University, Canberra.

Orians GH (1975). Diversity, stability and maturity in natural ecosystems. In *Unifying concepts in ecology*. Edited by WH van Dobben and RH Lowe-McConnell. Pages 139-150. Dr Junk, The Hague.

Osland MJ, Enwright NM, Day RH, Gabler CA, Stagg CL and Grace JB (2016). Beyond just sea-level rises: considering macroclimatic drivers within coastal wetland vulnerability assessments to climate change. *Global Change Biology* 22: 1-11.

Paijmans K, Galloway RW, Faith DP, Fleming PM, Haantjens HA, Heyligers PC, Kalma JD & Loffler E (1985). *Aspects of Australian wetlands*. CSIRO Australia Division of Water and Land Resources Technical Paper 44: 1-71.

Pendleton L, Donato DC, Murray BC, Crooks S, Jenkins WA. Sifleet S, *et al*. (2012). Estimating global 'Blue Carbon' emissions from conversion and degradation of vegetated coastal ecosystems, *PLoS ONE* 7, e43542.

Peterson GD (2005). Ecological management: control, uncertainty, and understanding. In *Ecological paradigms lost: Routes of theory change*. Edited by Cuddington K and Beisner BE. Pages 371-395. Elsevier, Amsterdam.

Peterson GD, Cummings GS and Carpenter SR (2003). Scenario planning: a tool for conservation in an uncertain world. *Conservation Biology* 17: 358-366.

Pimm, S. L. 1991. The balance of nature? University of Chicago Press, Chicago, Illinois, USA.

Poloczanska *et al*. (2007). Climate change and Australian marine life. *Oceanography and Marine Biology: Annual Review* 45: 407-478.

Prahalad VN, Kirkpatrick JB & Mount RE (2011). Tasmanian coastal saltmarsh community transitions associated with climate change and relative sea level rise 1975−2009. *Australian Journal of Botany* 59: 741-748.

Pratolongo PD, Kirby JR, Plater A & Brinson MM (2009). Temperate coastal wetlands: morphology, sediment processes, and plant communities. In *Coastal wetlands. An integrated ecosystem approach.* Edited by Perillo GME, Wolanski E, Cahoon DR & Brinson MM. Pages 89-118. Elsevier, Amsterdam.

Pressey RL & Adam P (1995). A review of wetland inventory and classification in Australia. *Vegetation* 118: 81-101.

Rahmstorf S (2010). A new view on sea level rise. *Nature Reports Climate Change* 4: 44-45.

Rahmstorf S, Cazenave A, Church JA, Hansen JE, Keeling RF, Parker DE & Somerville RCJ (2007). Recent climate observations compared to projections. *Science* 316: 709.

Ramsar Convention Secretariat (2006) *The Ramsar Convention manual: a guide to the Convention on Wetlands (Ramsar, Iran, 1971)*. 4th Edition. Ramsar Convention Secretariat, Gland.

Rahmstorf S, Cazenave A, Church JA, Hansen JE, Keeling RF, Parker DE and Somerville RCJ (2007). Recent climate observations compared to projections. *Science* 316: 709.

Rogers K, Saintilan N & Copeland C (2012). Modelling wetland surface elevation dynamics and its application to forecasting the effects of sea-level rise on estuarine wetlands. *Ecological Modelling* 244: 148-157.

Rogers K, Saintilan N & Copeland C (2014). Managed retreat of saline coastal wetlands: challenges and opportunities identified from the Hunter River estuary, Australia. *Estuaries and Coasts* 37: 67-78.

Rogers K, Boon PI, Branigan S, Duke NC, Field CD, Fitzsimons JA, Kirkman H, MacKenzie JR & Saintilan N (2016). The state of legislation and policy protecting Australia's mangrove and salt marsh and their ecosystem services. *Marine Policy* 72: 139-155.

Roy PS, Williams RJ, Jones AR, Yassini I, Gibbs PJ, Coates B, West RJ, Scanes PR, Hudson JP and Nichol S (2001). Structure and function of south-east Australian estuaries. *Estuarine, Coastal and Self Science* 53: 351-384.

Saintilan N & Williams RJ (1999). Mangrove transgression into saltmarsh environments in south-east Australia. *Global Ecology and Biogeography* 8: 117-124.

Saintilan N (2009). Distribution of Australian saltmarsh plants. In *Australian saltmarsh ecology*. Edited by Saintilan N. Pages 23-52. CSIRO Publishing, Melbourne.

Semeniuk V and Semeniuk CA (1997). A geomorphic approach to global classification for natural inland wetlands and rationalization of the system used by the Ramsar Convention − a discussion. *Wetlands Ecology and Management* 5: 145-158.

Silliman BR, van de Koppel J, Bertness MD, Stanton LE & Mendelssohn IA (2005). Drought, snails, and large-scale die-off of southern US salt marshes. *Science* 310: 1803-1806.

Sinclair SJ and Sutter GR (2008). *Estuarine wetland vegetation mapping, Glenelg Hopkins CMA*. Technical Report Series No. 178, Arthur Rylah Institute, Heidelberg.

Sjerp E, Martin B, Riedel P & Bird ECF (2002). *Gippsland Lakes shore erosion and revegetation strategy*. Report to Gippsland Coastal Board.

Sjerp E (2007). *Physical impacts of climate change on the Gippsland Lakes*. Report to Gippsland Lakes Taskforce. Ethos NRM, Bairnsdale.

Sinclair Knight Merz (2013). *Indicative assessment of climate change vulnerability for wetlands in Victoria*. Report prepared for Department of Sustainability and Environment (now DELWP)

Spatial Vision (2014). *NRM planning for climate change: Final project report 1 – Impact and vulnerability assessment process and spatial outputs*. Report prepared for Victorian Catchment Management Authorities (on behalf of seven Victorian CMAs)

Spencer T & Möller I (2013). Mangrove systems. In *Treatise on geomorphology. Volume 10: Coastal geomorphology*. Pages 360-391. Elsevier, Amsterdam.

Steffen W, Burbridge AA, Hughes L, Kitching R, Lindenmayer D, Musgrove W, Stafford Smith M & Werner PA (2009 a). *Australia's biodiversity and climate change: a strategic assessment of the vulnerability of Australia's biodiversity to climate change*. Report to the Natural Resources Ministerial Council. Available on-line at http://www.climate change.gov.au/impacts/pubs/biodiversity-vulnerability-assessment.pdf

Steffen W, Burbridge AA, Hughes L, Kitching R, Lindenmayer D, Musgrove W, Stafford Smith M & Werner PA (2009 b). *Australia's biodiversity and climate change: a strategic assessment of the vulnerability of Australia's biodiversity to climate change. Technical synthesis*. Report to the Natural Resources Ministerial Council. Available on-line at http://www.climate change.gov.au/impacts/pubs/technical-synthesis.pdf

Tagliapietra D, Sigovini M and Ghirardini AV (2009). A review of terms and definitions to categorise estuaries, lagoons and associated environments. *Marine and Freshwater Research* 60: 497-509.

Timbal B & Jones DA (2008). Future projections of winter rainfall in southeast Australia using a statistical downscaling technique. *Climatic Change* 86: 165-187.

Voice M, Harvey N & Walsh K (2006). *Vulnerability to climate change of Australia's coastal zone: analysis of gaps in methods, data and systems thresholds*. Australian Greenhouse Office, Canberra.

Walsh K (2004). *Climate change and coastal response.* CRC for Coastal Zone, Estuary and Waterway Management, Indooroopilly.

Water Technology (2013). *Latrobe estuary environmental water requirements study*. Report to West Gippsland CMA.

Western Port Greenhouse Alliance (2008). *Impacts of climate change on settlements in the Western Port region. People, property and places*. Final report, June 2008.

Westgate MJ, Likens GE, Lindenmayer DB (2013) Adaptive management of biological systems: a review. *Biological Conservation* 158, 128−139.

Woodroffe CS (2002). *Coast: form, process and evolution*. Cambridge University Press, Cambridge.

Woodfoffe CD & Davies G (2009). The morphology and development of tropical coastal wetlands. In *Coastal wetlands. An integrated ecosystem approach.* Edited by Perillo GME, Wolanski E, Cahoon DR & Brinson MM. Pages 65-88. Elsevier, Amsterdam.

Worley Parsons (2011). *Development of a marine and asset prioritisation Gippsland Coastal and Marine Assets Framework*. Final Report. Report to Gippsland Coastal Board.

Zann LP & Dutton I (2000). The social values and perceptions of Australians concerning the marine environment. In *State of the Environment Report for Australia. Technical summary*. Edited by LP Zann. Pages 127-134. Ocean Rescue 2000 & Department of the Environment, Sport and Territories, Canberra.

Appendix A. Discussion supporting definitions of coastal wetlands

A1 Definition of the term 'coastal'

The words 'coastal' or 'coastal zone', although widely used in a great many contexts for management, geomorphological, ecological and demographic investigations, are rarely defined consistently or unequivocally in the documents in which they are used. Two problems are apparent. First, often the spatial delimitation is simply left undefined, with the expectation that readers implicitly know what 'coastal' means and where the coastal zone ends and the non-coastal or inland zone starts (e.g. as in Lazarow *et al* 2006; National Resource Management Ministerial Council 2006). This vagueness is actually quite problematic, as it's not clear what parts of the country are considered within scope and what parts are extraneous. In some studies a definition is provided but it is dense and legalistic, as is the case for the definition adopted by the European Water Framework Directive (Borja 2005).

The second problem is that different disciplines can take 'the coast' to mean different things. As noted by the United Nations Food and Agriculture Organisation (2012) the term means different things according to whether the topic of interest is management, demographics, geography or ecosystem dynamics[19]. Thus demographers, geomorphologists, ecologists and coastal-zone managers are likely to have quite different understandings of the term 'coastal'. This presents a dilemma for the current project, as all four groups will have some interest in the effect and management of climate change on Victorian coastal wetlands. A critical first step is therefore to define operationally what is meant by 'coastal'.

A1.1 Generic definitions of the coastal zone

The first definition provided by Google[20] is the one adopted by the World Bank in 1996:

> *The coastal zone is the interface where the land meets the ocean, encompassing shoreline environments as well as adjacent coastal waters. Its components can include river deltas, coastal plains, wetlands, beaches and dunes, reefs, mangrove forests, lagoons, other coastal features.*

This definition is similar to the delimitation provided by the US Coastal Zone Management Act of 1972[21]:

> *Coastal zone means the coastal waters (including the land therein and thereunder) and the adjacent shorelands (including the waters therein and thereunder), strongly influenced by each and in proximity to the shorelines of the several coastal states, and includes islands, transitional and intertidal areas, salt marshes, wetlands and beaches.*

In Victoria, the coast is defined in the *2014 Victorian Coastal Strategy*, somewhat tautologically, as 'coastal, estuarine and marine environments' (page 6), including the nearshore marine environment, foreshores or coastal Crown land up to 200 m from the high water mark, and rivers and drainage systems that affect the coastal zone[22]. This, however, is merely one of a number of definitions applied to 'coastal', as outlined in Table A1-1.

---

[19] http://www.fao.org/docrep/008/a0266e/a0266e07.htm

[20] https://www.google.com.au/?gws_rd=ssl#q=definition+coastal+zone

[21] http://www.unep.org/NairobiConvention/docs/Coastal_zone_definition_and_geographic_coverage_of_the_ICZM_Protocol-Julien_Rochette.pdf

[22] http://www.vcc.vic.gov.au/assets/media/menu_files/VCS_2014.pdf

Table A1-1: Some existing generic definitions of the term 'coastal' or 'coastal zone'. Adapted from FAO's Defining the Coast and Frameworks (http://www.fao.org/docrep/008/a0266e/a0266e07.htm)

Source	Definition	Notes
United Nations Millennium Assessment	The coastal zone is one of six reporting categories defined by (i) a central concept and (ii) boundary limits for mapping. *Central Concept: interface between ocean and land, extending seawards to about the middle of the continental shelf and inland to include all areas strongly influenced by the proximity to the ocean. Boundary Limits for Mapping: area between 50 m below mean sea level and 50 m above the high tide level or extending landward to a distance 100 km from shore. Includes coral reefs, intertidal zones, estuaries, coastal aquaculture and sea grass communities*. The reporting categories are not mutually exclusive: e.g. *a wetland ecosystem in a coastal region may be examined both in the MA analysis of coastal systems as well as in its analysis of inland water systems.* Some differentiation is made between the coastal zone and other adjacent reporting categories based on the definition of boundary limits for mapping. For example, the coastal zone has a shared boundary with boarding marine systems (*> 50 m depth*).	The United Nations Millennium Assessment (MA) is an international work programme designed to meet scientific information needs concerning the consequences of ecosystem change and available options for response. Documentation: MA (2003); www.millenniumassessment.org/
Ramsar Convention	The Ramsar definition of wetlands accounts for a wide variety of coastal habitats. The Ramsar Classification System for Wetland Type lists the following types of coastal wetlands: permanent shallow marine waters; marine subtidal aquatic beds; coral reefs; rocky marine shores; sand, shingle or pebble shores; estuarine waters; intertidal mud, sand or salt flats; intertidal marshes; intertidal forested wetlands; coastal brackish/saline lagoons; coastal freshwater lagoons, and karst and other subterranean hydrological systems. Under the original Convention on Wetlands, wetlands are described as: areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres... [Wetlands] may incorporate adjacent riparian and coastal zones, islands or bodies of marine water deeper than six metres at low tide lying within the wetland.	The Ramsar Convention on Wetlands held in Ramsar, Iran, in 1971, covers all aspects of wetland conservation, recognizing wetlands' extreme importance for biodiversity conservation and the well-being of human communities. Documentation: Ramsar Convention on Wetlands (1971) and associated key documents (Articles 1.2 and 2.1); www.ramsar.org/
United Nations Environment Program	An exact definition and spatial extent is not specified for coastal habitats that are part of the CME assessment. Instead an adaptable approach is proposed to determine the scope, based on existing assessment approaches: the geographical structure of the assessment has to be flexible and based on natural, political and institutional realities. Existing geographical and programmatic structure ... should be used where appropriate. The large variety of habitats in coastal waters is noted, including coastal wetlands, estuaries and deltas, mangrove, coastal reef and seagrass beds. ICARM guidelines identify the area of concern as encompassing the catchment, the coastal zone and the nearshore coastal waters. Four interacting zones are taken into consideration: coastal waters, the coastal strip, estuary, and the coastal plain.	The United Nations Environment Programme (UNEP) is developing a module for the Assessment of the Coastal and Marine Environment (CME) as a contribution to the planned Global Marine Assessment (GMA). This contribution encompasses and is expanding upon existing assessment initiatives for the major coastal and marine ecosystems. Multiple other coastal-related initiatives have been or are being conducted, such as the programme on Integrated Coastal Area and River Basin Management (ICARM) relevant to the terrestrial coast. Documentation: UNEP (2004); UNEP/MAP/PAP (1999); www.unep-wcmc.org/marine/
Coastal Ocean Observations Module of	Coastal, as defined for use in the Coastal Module of GOOS, refers to regional mosaics of habitats including intertidal habitats (mangroves, marshes, mud flats, rocky shores, sandy beaches), semi-enclosed bodies of water (estuaries, sounds, bays, fjords, gulfs, seas), benthic	The Coastal Ocean Observations Module of the Global Ocean Observing System (C-GOOS) has been developed with the goal of monitoring,

the Global Ocean Observing System (C-GOOS)	habitats (coral reefs, sea grass beds, kelp forests, hard and soft bottoms) and the open waters of the coastal ocean to the seaward limits of the Exclusive Economic Zone (EEZ), i.e. from the head of the tidal waters to the outer limits of the EEZ. The definition of coastal zone is adopted from Nicholls and Small (2002): the land margin within 100 km of the coastline or less than 100 m above mean low tide, whichever comes first.	assessing, and predicting the effects of natural variations and human activities on the marine environment and ecosystems of the coastal ocean. Documentation: UNESCO (2003c); www.ioc.unesco.org/goos/coop.htm\
DELWP Victorian Wetland Inventory	The area of tidal influence (classified as either 'Marine – tidal wetlands in bays' or 'Estuarine – semi-enclosed tidal wetlands').	The 2013 inventory of wetlands brings together the most recent wetland data sets from a number of sources. It updates the state's first complete wetland inventory completed in 1994 and applied the Australian National Aquatic Ecosystem Classification Framework. Documentation: DEPI (2013a).
Interim Australian National Aquatic Ecosystems (ANAE) Classification Framework (Aquatic Ecosystems Task Group, 2012)	Identifies two coastal aquatic systems: • Marine systems consist of that portion of open ocean overlying the continental shelf and its associated high-energy coastline down to a depth of 6 metres below Lowest Astronomical Tide (LAT). Marine habitats are exposed to the waves and currents of the open ocean. • Estuarine systems (deep-water habitats, tidal wetlands, lagoons, salt marshes, mangroves etc.) are the component parts of estuaries i.e. those areas that are semi-enclosed by land with a permanently or intermittently open connection with the ocean, and where ocean water can be diluted by freshwater runoff from the land.	The ANAE is a broad-scale, semi-hierarchical, attribute-based scheme, which provides a nationally consistent, flexible framework for classifying different aquatic ecosystems and habitats including rivers, floodplains, lakes, palustrine wetlands, estuaries and subterranean ecosystems. Documentation: Aquatic Ecosystems Task Group, 2012. https://www.environment.gov.au/water/publications/aquatic-ecosystems-toolkit-module-2-interim-anae-classification-framework
Indicative Assessment of Climate Change Vulnerability for Wetlands in Victoria (SKM, 2013)	The area within 5 km of the coast that is classified as saline or mapped with coastal Ecological Vegetation Classes (EVCs) dependant or tolerant of saline conditions (i.e. estuarine reedbed, mangroves, coastal salt marsh)	The Indicative Assessment of Climate Change Vulnerability for wetlands in Victoria was a vulnerability assessment with a particular emphasis on understanding the likely change sin hydrological regimes and the regional distribution of these changes across Victoria. Documentation (SKM, 2013). http://www.depi.vic.gov.au/__data/assets/pdf_file/0016/242710/Wetland-vulnerability-to-climate-change-Victoria.pdf
United Nations Millennium Assessment	The coastal zone is one of six reporting categories defined by (i) a central concept and (ii) boundary limits for mapping. Central Concept: interface between ocean and land, extending seawards to about the middle of the continental shelf and inland to include all areas strongly influenced by the proximity to the ocean. Boundary Limits for Mapping: area between 50 m below mean sea level and 50 m above the high tide level or extending landward to a distance 100 km from shore. Includes coral reefs, intertidal zones, estuaries, coastal aquaculture and sea grass communities. The reporting categories are not mutually exclusive: e.g. a wetland ecosystem in a coastal region may be examined both in the MA analysis of coastal systems as well as in its analysis of inland water systems. Some differentiation is made between the coastal zone and other adjacent reporting categories based on the definition of boundary limits for mapping. For example, the coastal zone has a shared boundary with boarding marine systems (> 50 m depth).	The United Nations Millennium Assessment (MA) is an international work programme designed to meet scientific information needs concerning the consequences of ecosystem change and available options for response. Documentation: MA (2003); www.millenniumassessment.org

A1.2 Discipline-based definitions

Coastal-zone managers commonly define the coastal zone with reference to the interaction between oceanic and terrestrial processes and uses. Kay and Alder (1998), for example, defined coastal areas as areas that '…contain land which interacts with the ocean in some way, and ocean space which interacts with the land'. Similarly, Carter (2013) noted that the coastal zone was '…that space in which terrestrial environments influence marine (or lacustrine) environments and vice versa. The coastal zone is of variable width and may also change in time'.

Geomorphologists define the coast as the interface between the land and the sea, with the shoreline as the actual margin between the two (e.g. see Woodroffe 2002, page 2; Bird 2008, page 3). The 'coast' more generally though is a much broader concept, and again as noted by Woodroffe (2002) includes areas above and below the water. Confusion arises when attempts are made to spatially delimit these boundaries. Woodroffe (2002) concluded that the 'coastal zone' was a broad transitional area in which terrestrial environments influenced marine environments and vice-a-versa. Other coastal geomorphologists are more prescriptive. Bird (2008, page 2, 3), for example, adopted a similar general definition of the coast to Woodroffe: 'the zone where land, sea and air … meet and interact', but limited the coastline much more closely, to mean 'the edge of the land at the limit of normal spring high tides; the subaerial [i.e., surface] land margin, often marked by the seaward boundary of terrestrial vegetation'. Thus under Bird's definition, the coast extends only to the nearshore zone and to the limit where marine influences extend landward, including into coastal lowlands, dunes, lagoons and swamps.

Geographers and demographers often take a different approach. In the USA, for example, 'coastal counties' within individual States are considered for demographic purposes as those that have 15% or more of their total land area located within a catchment that drains to the sea (Crowell *et al*. 2007). Other demographers adopt a different definition. Nicholls and Small (2002), for example, defined 'near-coastal' for population studies as areas that were less than 100 m above mean sea level and within 100 km of the shoreline.

Ecologists take a different approach again, and they often define coastal systems in terms of the habitats that occur within coastal areas: ' Coral reefs, mangroves, tidal and non-tidal wetlands, sea grass beds, barrier islands, estuaries, peat swamps, lagoons, river reaches, deltas, coastally restricted forests, sea and land ice and other terrestrial ecosystems constitute the integrated, cross boundary coastal zone' (FAO 2012, page 1).

A1.3 Assessment of various options for a practical definition

This analysis shows there is no single compelling operational definition of what the word 'coastal' means. The variance in definitions should not be seen as an insurmountable issue. The Nairobi Convention on the coastal zone advised that it was not possible to devise a precise boundary for the coastal zone and that flexibility was required according to the aims of the investigation or management plan:

> *'Its precise delimitation depends directly on the problem posed initially. The limits should therefore extend into the sea and land just as far as required by the objectives of the management plan'*[23].

One initially attractive option is to delimit coastal aquatic systems as those that occur on the seaward side of the Great Divide. This works well for coastal rivers and their wetlands in Queensland and New South Wales. The short rivers that rise on the eastern side of the Great Divide and discharge directly into the Pacific Ocean, such as the Brisbane River in Queensland and the great drowned river valleys of the Clarence, Manning, Hawkesbury and Clyde Rivers in New South Wales are then clearly differentiated from the western-flowing rivers of the inland of these two States. As the system works well for rivers, it might work well also for wetlands. The definition also works for rivers in eastern Victoria, where the coastal Thurra, Nicholson and Mitchell Rivers, for example, south of the Divide can be clearly differentiated from the inland Kiewa and Ovens Rivers north of the Divide. It works well for the small coastal plain south of the Great Divide, in the Otways and along the central coast (e.g. the Maribyrnong River). But it does not work for rivers and other aquatic systems in far-western Victoria. One would be hard pressed to call the Glenelg River at

[23] http://www.unep.org/NairobiConvention/docs/Coastal_zone_definition_and_geographic_coverage_of_the_ICZM_Protocol-Julien_Rochette.pdf

Harrow near the western Grampians in the Wimmera a coastal river, even though it discharges to the sea at Nelson and the Grampians marks the western-most extent of the Divide. It is also unclear whether it could apply usefully to the Snowy River, which flows south of the Divide and debouches to the coast at Marlo. The lower reaches of this river around Orbost are clearly coastal, but those upstream, around Suggan Buggan, near the New South Wales border, clearly are not.

A second option is to include as coastal only those aquatic systems that experience tidal influence, as is done in the Victorian Wetland Inventory. This is too restrictive, as a large number of brackish-water wetlands along the Victorian coast are not tidal; the large Ramsar-listed wetlands of the lower Latrobe River, for example, including the saline Dowd Morass and Lake Coleman are strongly marine-influenced but not subject to any tidal influence at all (Water Technology 2013). This definition would also exclude freshwater systems within close proximity to the sea that experience a maritime influence but are not connected to the ocean, such as dune-system lakes and supratidal wetlands.

A third option, again hydrological, is to include only those wetlands that are estuarine. If one accepts the definition of an estuary as a body of water that experiences measurable dilution of ocean waters by freshwater (Tagliapietra *et al*. 2009), then again many wetlands that should be included in the study are excluded. Estuarine wetlands might not necessarily to tidal (e.g. the case of the lower Latrobe River wetlands above) but many wetlands along the Victorian coast that experience an oceanic influence are not in estuaries and would thus be excluded. Again this includes freshwater wetlands near the shore and subject to marine influence, such as wetlands in the swales of sand-dune systems (e.g. Ewings Morass in East Gippsland) and plant communities subject to salt splash. Moreover, the large embayments of the Victorian coast, such as Port Phillip Bay, Western Port and Corner Inlet are not estuaries in the sense that they experience substantial dilution by freshwater inflows. They are simply marine embayments, with near-oceanic salinity regimes. They also would be excluded if the term coastal were defined as synonymous with the term estuarine.

Demographic and ecologically inspired definitions lead to no greater clarity, although as shown later it is necessary to invoke an ecological description of the various types of wetlands that do occur in the coastal zone and are thus assessed within this project.

A1.4 The proposed definition of 'coastal'

The definition adopted for the current project is that the coastal zone is ***the area around the shoreline of Victoria between 0 and 10 m AHD***. This definition has a number of desirable features. It is short and simple, spatially explicit and easily applied with existing information. It can be applied to the entire Victorian coast, captures areas that experience a strong marine influence and all other 'coastal' systems that are likely to be impacted by climate change (e.g. coastal floodplains and dune systems). Section 2.3 in the report outlines this diversity of wetland types and the subdivisions necessary for all to be included in the DSF.

A2 Definition of the term 'coastal'

Of all habitat types, wetlands are among the most difficult to define unequivocally because they have soils (or sediments) and are thus not totally aquatic systems such as planktonic or pelagic environments. But they also have standing water, at least for some of the time, and are thus also not truly terrestrial. The dual nature of wetlands has led to their definition being varied, often confusing, and sometimes even contradictory (Mitsch and Gosselink 1993). Notwithstanding the problems with definition, it is widely acknowledged that wetlands commonly share four characteristics:

1. Water is present, either at the surface or within the root zone, for at least some of the time.
2. The water moves very slowly or is static (i.e., wetlands are lentic environments) unlike the case with flowing-water (or lotic) aquatic systems, such as rivers. Note that for coastal wetlands the speed of water flow may be modified by tidal influences.
3. Waterlogging produces soils with anaerobic or anoxic characteristics that are quite unlike 'normal' terrestrial soils.
4. Vegetation is adapted to wet conditions and/or flooding, with plants not tolerant of flooding largely absent or restricted to ones with an annual life cycle to avoid the inundated phase.

A2.1 Generic definitions

Various combinations of these characteristics have been invoked by different authors to define the term 'wetland'. Under the Ramsar Convention (Ramsar Convention Secretariat 2006) wetlands are defined under two Articles:

- Article 1.1: '...wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres.'
- Article 2.1: '[Wetlands] may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands'.

The origins of the 6 m depth limit are obscure, but are thought to be based on the maximum depth to which sea ducks can dive whilst feeding (Ramsar Convention Secretariat 2006).

Many wetland researchers and managers believe this definition to be too broad to be useful. Pressey and Adam (1995), in their review of wetland inventory and classification in Australia, note that most Australian interpretations depart substantially from the Ramsar proscription. They argued that the Ramsar definition was adopted mostly because of its wide use overseas and for the sake of consistency, rather than for any overwhelming theoretical reason.

One of the most widely used definitions comes from the US Fish and Wildlife Service (Cowardin *et al*. 1979, 1989). It defined wetlands as:

> *'… lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes …; (2) the substrate is predominantly undrained hydric soil… and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year'.*

Paijmans *et al*. (1985) undertook a comprehensive review of Australian wetlands and defined wetlands as:

> *'…land permanently or temporarily under water or waterlogged. Temporary wetlands must have surface water or waterlogging of sufficient frequency and/or duration to affect the biota. Thus the occurrence, at least sometimes, of hydrophytic vegetation or use by waterbirds are necessary attributes'.*

In a widely used review, the New Zealand wetland ecologist Howard-Williams (1985, page 393) defined wetlands as:

> *'an area where the water table is at or above the land surface for long enough each year to promote the formation of hydric soils and to support the growth of aquatic vegetation much of which is emergent (photosynthetic organs above the water surface)'.*

The advantage in using a definition such as Howard-Williams' (1985), which includes a vegetative component, over one like Paijmans *et al*. (1985), which does not, is that wetlands can be discriminated from other lentic environments, such as farm ponds and treatment lagoons, that mostly lack the emergent vegetation that many people consider typifies a wetland.

A2.2 Extension to the coastal zone

The limitation with all these definitions is that they have been largely developed with an eye to inland wetland systems. In such systems there is no need to account for or include tidal or maritime effects. Inundation and the formation of hydric soils often comes about because of the wetland's location on a floodplain, in a depressions subject to localised runoff, or as a consequence of groundwater expressing at the surface. But in coastal wetlands, a large majority (but not all, as discussed previously) of wetlands are influenced by the tides to various extents. In these cases, it is tidal inundation, not overbank riverine flow or groundwater discharge, that most often results in recurrent inundation, the formation on anaerobic sediments, and the development of a specialised flora.

In the now elderly *Wetlands conservation program for Victoria* (Department of Conservation, Forests and Lands 1988, page 3), the possibility that wetlands could be inundated by tides was made explicit. It described wetlands along the lines of the Ramsar definition:

> *'…areas of marsh, fen, peatland or water, whether natural or artificial, permanent, seasonal or cyclical, with water that is static or flowing, fresh, brackish or salt, including mudflats and mangrove areas exposed at low tide'.*

The Statewide wetland inventory (DEPI, 2013a), which applies the Victorian Wetland Classification Framework (consistent with ANAE classification), adopts four categories of wetlands systems:

- Lacustrine – Non-tidal wetlands with less than 30% cover of emergent aquatic vegetation
- Palustrine – Non-tidal wetlands with more than 30% cover of emergent aquatic vegetation
- Semi-enclosed tidal wetlands
- Tidal wetlands in bays

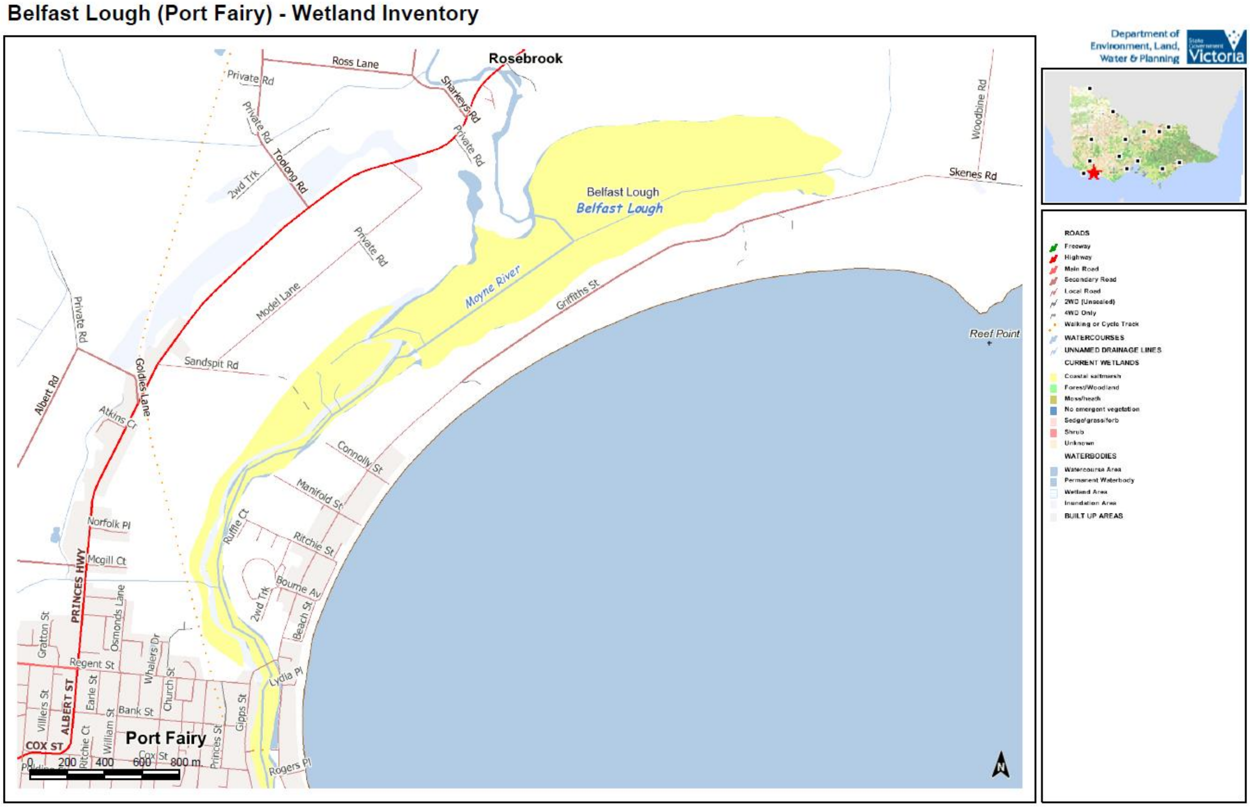
In order to distinguish between non-tidal wetlands and tidal wetlands, the following rules were applied in the inventory:

1. *'Assign wetlands that have more than 70% of their area outside the Victorian landmass as tidal*
2. *Assign wetlands that have less than 70% of their area outside the Victorian landmass, but more than 70% of their area intersecting Victorian Saltmarsh EVC mapping as tidal*
3. *Assign wetlands that have less than 70% of their area outside the Victorian landmass, but more than 70% of their area intersecting estuaries as tidal'.*

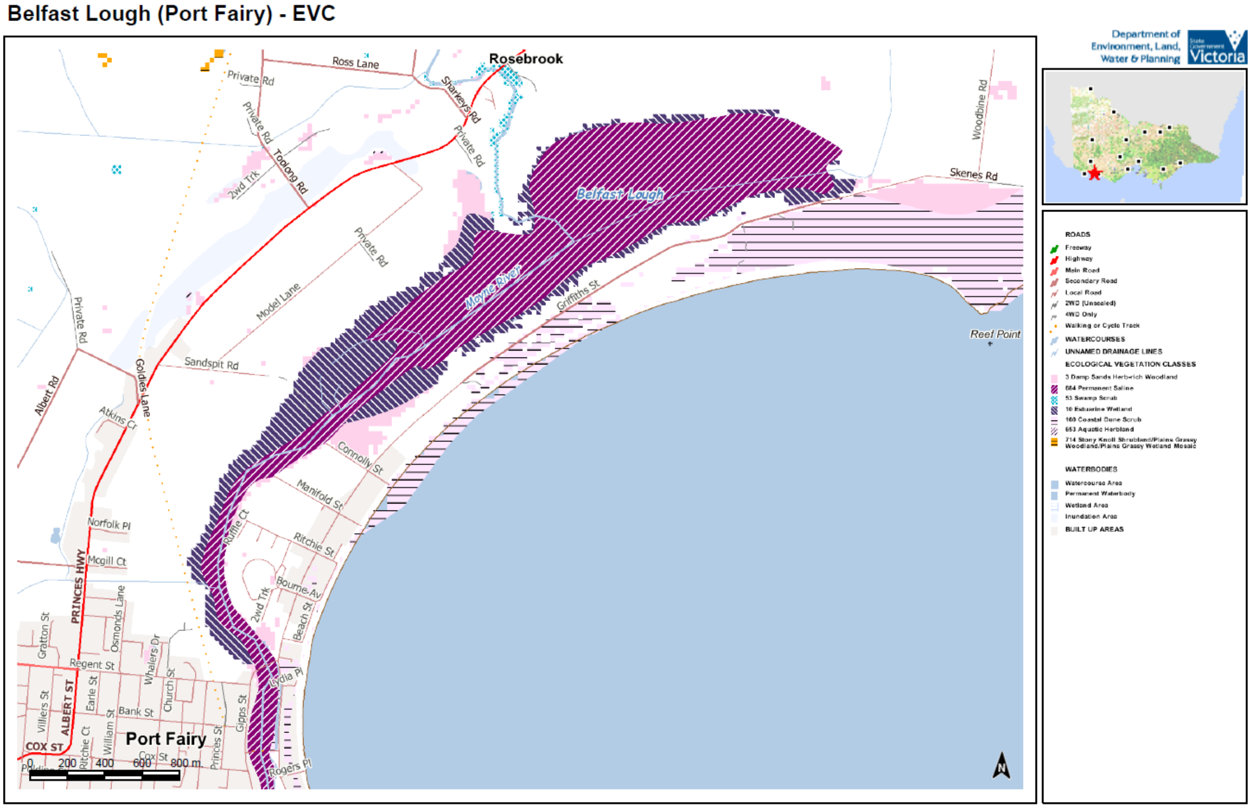
Tidal wetlands were then classified into one of two possible classes, marine or estuarine. Those tidal wetlands classified as being 'marine' were those wetlands where freshwater inflows were expected to play a minor part in their ecology and included Corner Inlet, Shallow Inlet, Anderson Inlet, Western Port Bay (including Quail Island, Rhyll Inlet and The Duck Splash) and wetlands within Port Phillip Bay (including Mud Islands). All other tidal wetlands were classified as estuarine (DEPI, 2013a).

Appendix B. Comparison of wetlands shown in State wetland inventory and in EVC mapping

Belfast Lough (Port Fairy) - Wetland Inventory



Belfast Lough (Port Fairy) - EVC



Appendix C. EVCs developed for Habitat Hectares program – wetland and estuary dependent ECVs identified

EVC No.	EVC Name	EVC Group Name	Wetland/ Estuary dependent EVC (DELWP, 2015)	Benchmark Wetland EVC (DEPI, 2013b)	Final wetland classification for this project
1	**Coastal Dune Scrub/Coastal Dune Grassland Mosaic**	Coastal Scrubs Grasslands and Woodlands	No	No	No
2	**Coast Banksia Woodland**	Coastal Scrubs Grasslands and Woodlands	No	No	No
3	**Damp Sands Herb-rich Woodland**	Herb-rich Woodlands	No	No	No
4	**Coastal Vine-rich Forest**	Rainforests	No	No	No
5	**Coastal Sand Heathland**	Heathlands	No	No	No
6	**Sand Heathland**	Heathlands	No	No	No
7	**Clay Heathland**	Heathlands	No	No	No
8	**Wet Heathland**	Heathlands	Yes	Yes	Yes
9	**Coastal Saltmarsh**	Salt-tolerant and/or succulent Shrublands	Yes	Yes	Yes
10	**Estuarine Wetland**	Wetlands	Yes	Yes	Yes
11	**Coastal Lagoon Wetland**	Wetlands	Yes	Yes	Yes
12	**Wet Swale Herbland**	Wetlands	Yes	Yes	Yes
13	**Brackish Sedgeland**	Wetlands	Yes	Yes	Yes

14	**Banksia Woodland**	Lowland Forests	No	No	No
15	**Limestone Box Forest**	Lowland Forests	No	No	No
16	**Lowland Forest**	Lowland Forests	No	No	No
17	**Riparian Scrub/Swampy Riparian Woodland Complex**	Riparian Scrubs or Swampy Scrubs and Woodlands	No	Yes	Yes
18	**Riparian Forest**	Riparian Scrubs or Swampy Scrubs and Woodlands	Yes	No	Yes
21	**Shrubby Dry Forest**	Dry Forests	No	No	No
22	**Grassy Dry Forest**	Dry Forests	No	No	No
23	**Herb-rich Foothill Forest**	Dry Forests	No	No	No
27	**Blackthorn Scrub**	Rocky Outcrop or Escarpment Scrubs	No	No	No
29	**Damp Forest**	Wet or Damp Forests	No	No	No
30	**Wet Forest**	Wet or Damp Forests	No	No	No
31	**Cool Temperate Rainforest**	Rainforests	No	No	No
32	**Warm Temperate Rainforest**	Rainforests	No	No	No
34	**Dry Rainforest**	Rainforests	No	No	No
45	**Shrubby Foothill Forest**	Dry Forests	No	No	No
47	**Valley Grassy Forest**	Dry Forests	No	No	No
48	**Heathy Woodland**	Heathy Woodlands	No	No	No
53	**Swamp Scrub**	Riparian Scrubs or Swampy Scrubs and Woodlands	Yes	Yes	Yes
55	**Plains Grassy Woodland**	Plains Woodlands or Forests	No	No	No

56	**Floodplain Riparian Woodland**	Riverine Grassy Woodlands or Forests	Yes	Yes	Yes
68	**Creekline Grassy Woodland**	Riverine Grassy Woodlands or Forests	No	No	No
72	**Granitic Hills Woodland**	Box Ironbark Forests or dry/lower fertility Woodlands	No	No	No
74	**Wetland Formation**	Wetlands	Yes	No	Yes
82	**Riverine Escarpment Scrub**	Rocky Outcrop or Escarpment Scrubs	No	No	No
83	**Swampy Riparian Woodland**	Riparian Scrubs or Swampy Scrubs and Woodlands	Yes	Yes	Yes
104	**Lignum Swamp**	Wetlands	Yes	Yes	Yes
123	**Riparian Forest/Warm Temperate Rainforest Mosaic**	Riparian Scrubs or Swampy Scrubs and Woodlands	No	No	No
125	**Plains Grassy Wetland**	Wetlands	Yes	Yes	Yes
132	**Plains Grassland**	Plains Grasslands and Chenopod Shrublands	No	No	No
133	**Limestone Pomaderris Shrubland**	Rocky Outcrop or Escarpment Scrubs	No	No	No
136	**Sedge Wetland**	Wetlands	Yes	Yes	Yes
140	**Mangrove Shrubland**	Salt-tolerant and/or succulent Shrublands	Yes	Yes	Yes
141	**Sandy Flood Scrub**	Riparian Scrubs or Swampy Scrubs and Woodlands	No	No	Yes
144	**Coast Banksia Woodland/Warm Temperate Rainforest Mosaic**	Rainforests	No	No	No
151	**Plains Grassy Forest**	Plains Woodlands or Forests	No	No	No
155	**Bird Colony Succulent Herbland**	Coastal Scrubs Grasslands and Woodlands	No	No	Yes
160	**Coastal Dune Scrub**	Coastal Scrubs Grasslands and Woodlands	No	No	No
161	**Coastal Headland Scrub**	Coastal Scrubs Grasslands and Woodlands	No	No	No

161	**Coastal Headland Scrub/Coastal Tussock Grassland Mosaic**	Coastal Scrubs Grasslands and Woodlands	No	No	No
163	**Coastal Tussock Grassland**	Coastal Scrubs Grasslands and Woodlands	No	No	No
165	**Damp Heath Scrub**	Heathlands	No	No	No
169	**Dry Valley Forest**	Dry Forests	No	No	No
172	**Floodplain Wetland Aggregate**	Wetlands	Yes	Yes	Yes
175	**Grassy Woodland**	Lower Slopes or Hills Woodlands	No	No	No
179	**Heathy Herb-rich Woodland**	Heathy Woodlands	No	No	No
181	**Coast Gully Thicket**	Coastal Scrubs Grasslands and Woodlands	No	No	No
191	**Riparian Scrub**	Riparian Scrubs or Swampy Scrubs and Woodlands	Yes	Yes	Yes
195	**Seasonally Inundated Shrubby Woodland**	Lower Slopes or Hills Woodlands	Yes	Yes	Yes
198	**Sedgy Riparian Woodland**	Riverine Grassy Woodlands or Forests	No	No	No
200	**Shallow Freshwater Marsh**	Wetlands	No	No	Yes
201	**Shrubby Wet Forest**	Wet or Damp Forests	No	No	No
203	**Stony Rises Woodland**	Plains Woodlands or Forests	No	No	No
233	**Wet Sands Thicket**	Riparian Scrubs or Swampy Scrubs and Woodlands	No	No	No
259	**Plains Grassy Woodland/Gilgai Wetland Mosaic**	Plains Woodlands or Forests	No	No	No
300	**Reed Swamp**	Wetlands	No	No	Yes
302	**Coastal Saltmarsh/Mangrove Shrubland Mosaic**	Salt-tolerant and/or succulent Shrublands	No	No	Yes
307	**Sand Heathland/Wet Heathland Mosaic**	Heathlands	Yes	No	No

309	**Calcareous Swale Grassland**	Coastal Scrubs Grasslands and Woodlands	No	No	No
311	**Berm Grassy Shrubland**	Coastal Scrubs Grasslands and Woodlands	No	No	No
316	**Shrubby Damp Forest**	Wet or Damp Forests	No	No	No
334	**Billabong Wetland Aggregate**	Wetlands	Yes	Yes	Yes
418	**Damp Sands Herb-rich Woodland/Heathy Woodland Complex**	Herb-rich Woodlands	No	No	No
636	**Brackish Lake Aggregate**	Salt-tolerant and/or succulent Shrublands	Yes	Yes	Yes
638	**Swamp Scrub/ Wet Heathland Mosaic**	Riparian Scrubs or Swampy Scrubs and Woodlands	No	No	Yes
641	**Riparian Woodland**	Riparian Scrubs or Swampy Scrubs and Woodlands	No	No	No
644	**Cinder Cone Woodland**	Lower Slopes or Hills	No	No	No
645	**Wet Heathland/Heathy Woodland Mosaic**	Heathlands	No	No	No
647	**Plains Sedgy Wetland**	Wetlands	Yes	Yes	Yes
651	**Plains Swampy Woodland**	Plains Woodlands or Forests	Yes	Yes	No
653	**Aquatic Herbland**	Wetlands	Yes	Yes	Yes
656	**Brackish Wetland**	Wetlands	Yes	Yes	Yes
666	**Riparian Shrubland/Escarpment Shrubland/Grassy Woodland Mosaic**	Riparian Scrubs or Swampy Scrubs and Woodlands	No	No	No
669	**Escarpment Shrubland/Damp Sands Herb-rich Woodland/Riparian Woodland/Swamp Scrub Mosaic**	Herb-rich Woodlands	No	No	No
675	**Escarpment Shrubland/Damp Sands Herb-rich Woodland/Swamp Scrub Mosaic**	Herb-rich Woodlands	No	No	No
680	**Freshwater Meadow**	Wetlands	No	No	No

681	**Deep Freshwater Marsh**	Wetlands	No	No	Yes
682	**Permanent Open Freshwater**	No native vegetation recorded	No	No	Yes
683	**Semi-Permanent Saline**	No native vegetation recorded	No	No	Yes
684	**Permanent Saline**	No native vegetation recorded	No	No	Yes
686	**Wet Heathland/Damp Heathland Mosaic**	Heathlands	No	No	No
687	**Swamp Scrub/Plains Grassland Mosaic**	Riparian Scrubs or Swampy Scrubs and Woodlands	No	No	Yes
688	**Swampy Riparian Woodland/Swamp Scrub Mosaic**	Riparian Scrubs or Swampy Scrubs and Woodlands	No	No	Yes
691	**Aquatic Herbland/Plains Sedgy Wetland Mosaic**	Wetlands	No	No	Yes
692	**Mangrove Shrubland/Coastal Saltmarsh/Berm Grassy Shrubland/Estuarine Flats Grassland Mosaic**	Salt-tolerant and/or succulent Shrublands	No	No	Yes.
695	**Dry Valley Forest/Swamp Scrub/Warm Temperate Rainforest Mosaic**	Riparian Scrubs or Swampy Scrubs and Woodlands	No	No	No
698	**Lowland Forest/Heathy Woodland Mosaic**	Lowland Forests	No	No	No
699	**Valley Grassy Forest/Swamp Scrub Mosaic**	Dry Forests	No	No	Yes
710	**Damp Heathland**	Heathlands	No	No	No
713	**Damp Sands Herb-rich Woodland/Damp Heathland/Damp Heathy Woodland Mosaic**	Herb-rich Woodlands	No	No	No
714	**Stony Knoll Shrubland/Plains Grassy Woodland/Plains Grassy Wetland Mosaic**	Plains Woodlands or Forests	No	No	No
719	**Grassy Woodland/Damp Sands Herb-rich Woodland Mosaic**	Herb-rich Woodlands	No	No	No
720	**Swamp Scrub/Aquatic Herbland Mosaic**	Riparian Scrubs or Swampy Scrubs and Woodlands	No	No	Yes
725	**Damp Sands Herb-rich Woodland/Riparian Woodland/Swamp Scrub Mosaic**	Herb-rich Woodlands	No	No	Yes

732	**Damp Sands Herb-rich Woodland/Plains Swampy Woodland/Aquatic Herbland Mosaic**	Herb-rich Woodlands	No	No	Yes
737	**Heathy Woodland/Limestone Woodland Mosaic**	Heathy Woodlands	No	No	No
740	**Damp Sands Herb-rich Woodland/Heathy Woodland/Sand Heathland Mosaic**	Herb-rich Woodlands	No	No	No
746	**Damp Heathland/Damp Heathy Woodland Mosaic**	Heathlands	No	No	No
762	**Damp Heathland/Sand Heathland Mosaic**	Heathlands	No	No	No
793	**Damp Heathy Woodland**	Heathy Woodlands	No	No	No
795	**Lowland Forest/Damp Sands Herb-rich Woodland Mosaic**	Lowland Forests	No	No	No
797	**Coastal Landfill/Sand Accretion**	No native vegetation recorded	No	No	No
851	**Stream Bank Shrubland**	Riparian Scrubs or Swampy Scrubs and Woodlands	No	No	No
858	**Coastal Alkaline Scrub**	Coastal Scrubs Grasslands and Woodlands	No	No	No
863	**Floodplain Reedbed**	Riverine Grassy Woodlands or Forests	No	No	Yes
875	**Blocked Coastal Stream Swamp**	Wetlands	Yes	Yes	Yes
876	**Spray-zone Coastal Shrubland**	Coastal Scrubs Grasslands and Woodlands	No	No	No
877	**Lowland Herb-rich Forest**	Lowland Forests	No	No	No
878	**Damp Sands Herb-rich Woodland/Swamp Scrub Complex**	Herb-rich Woodlands	No	No	Yes
879	**Coastal Dune Grassland**	Coastal Scrubs Grasslands and Woodlands	No	No	No
881	**Damp Sands Herb-rich Woodland/Heathy Woodland Mosaic**	Herb-rich Woodlands	No	No	No
891	**Plains Brackish Sedge Wetland**	Wetlands	No	No	Yes

892	**Heathy Woodland/Sand Heathland Mosaic**	Heathy Woodlands	No	No	No
895	**Escarpment Shrubland**	Plains Woodlands or Forests	No	No	No
897	**Plains Grassland/Plains Grassy Woodland Mosaic**	Plains Grasslands and Chenopod Shrublands	No	No	No
899	**Plains Freshwater Sedge**	Wetlands	No	No	Yes
900	**Coastal Saltmarsh/Coastal Dune Grassland/Coastal Dune Scrub/Coastal Headland Scrub Mosaic**	Coastal Scrubs Grasslands and Woodlands	No	No	Yes
902	**Gully Woodland**	Dry Forests	No	No	No
903	**Mangrove Shrubland/Estuarine Flats Grassland Mosaic**	Salt-tolerant and/or succulent Shrublands	No	No	Yes
904	**Coast Banksia Woodland/Swamp Scrub Mosaic**	Coastal Scrubs Grasslands and Woodlands	No	No	Yes
906	**Brackish Grassland/Swamp Scrub Mosaic**	Wetlands	No	No	Yes
909	**Coastal Dune Scrub/Bird Colony Succulent Herbland Mosaic**	Coastal Scrubs Grasslands and Woodlands	No	No	Yes
910	**Bird Colony Succulent Herbland/Coastal Tussock Grassland Mosaic**	Coastal Scrubs Grasslands and Woodlands	No	No	Yes
914	**Estuarine Flats Grassland**	Wetlands	Yes	Yes	Yes
915	**Aquatic Herbland/Swamp Scrub Mosaic**	Wetlands	No	No	Yes
919	**Coastal Headland Scrub/Coast Banksia Woodland Mosaic**	Coastal Scrubs Grasslands and Woodlands	No	No	No
921	**Coast Banksia Woodland/Coastal Dune Scrub Mosaic**	Coastal Scrubs Grasslands and Woodlands	No	No	No
922	**Coastal Alkaline Scrub/Bird Colony Succulent Herbland Mosaic**	Coastal Scrubs Grasslands and Woodlands	No	No	Yes
925	**Damp Sands Herb-rich Woodland/Swamp Scrub Mosaic**	Herb-rich Woodlands	No	No	Yes
927	**Plains Grassy Woodland/Swamp Scrub/Plains Grassy Wetland Mosaic**	Plains Woodlands or Forests	No	No	Yes

934	**Brackish Grassland**	Brackish/estuarine	Yes	Yes	Yes
935	**Estuarine Wetland/Estuarine Swamp Scrub Mosaic**	Wetlands	No	No	Yes
937	**Swampy Woodland**	Riparian Scrubs or Swampy Scrubs and Woodlands	Yes	Yes	Yes
985	**Sandy Beach**	No native vegetation recorded	No	No	No
986	**Rocky Shore**	No native vegetation recorded	No	No	No
989	**Cane Grass-Lignum Halophytic Herbland**	Coastal Scrubs Grasslands and Woodlands	No	No	No
991	**Water body - salt**	No native vegetation recorded	No	No	Yes
992	**Water Body - Fresh**	No native vegetation recorded	No	No	Yes
993	**Bare Rock/Ground**	No native vegetation	No	No	No
994	**Dunes**	No native vegetation recorded	No	No	No
998	**Water Body - man-made**	No native vegetation recorded	No	No	No
1106	**Damp Heathy Woodland/Lowland Forest Mosaic**	Heathy Woodlands	No	No	No
1107	**Water Body - estuary**	No native vegetation recorded	No	No	Yes
CDS	***Coastal Dry Saltmarsh***	*Salt-tolerant and/or succulent Shrublands*	*N/A*	*N/A*	*Yes*
CHS	***Coastal Hypersaline Saltmarsh***	*Salt-tolerant and/or succulent Shrublands*	*N/A*	*N/A*	*Yes*
CSA	***Coastal Saltmarsh Aggregate***	*Salt-tolerant and/or succulent Shrublands*	*N/A*	*N/A*	*Yes*
CSG	***Coastal Saline Grassland***	*Salt-tolerant and/or succulent Shrublands*	*N/A*	*N/A*	*Yes*
CTS	***Coastal Tussock Saltmarsh***	*Salt-tolerant and/or succulent Shrublands*	*N/A*	*N/A*	*Yes*
EW	***Estuarine Wetland***	*Wetlands*	*N/A*	*N/A*	*Yes*

MS	***Mangrove Shrubland***	*Salt-tolerant and/or succulent Shrublands*	*N/A*	*N/A*	*Yes*
N/A	***Seagrass (not mapped)***	*Seagrass*	*N/A*	*N/A*	*Yes*
SGS	***Saltmarsh-grass Swamp***	*Salt-tolerant and/or succulent Shrublands*	*N/A*	*N/A*	*Yes*
SISH	***Seasonally Inundated Sub-saline Herbland***	*N/A*	*N/A*	*N/A*	*Yes*
WSH	***Wet Saltmarsh Herbland***	*Salt-tolerant and/or succulent Shrublands*	*N/A*	*N/A*	*Yes*
WSS	***Wet Saltmarsh Shrubland***	*Salt-tolerant and/or succulent Shrublands*	*N/A*	*N/A*	*Yes*

Italics = wetlands mapped in P. I. Boon *et al*. 2014.

Appendix D. Regional Wetland Mapping

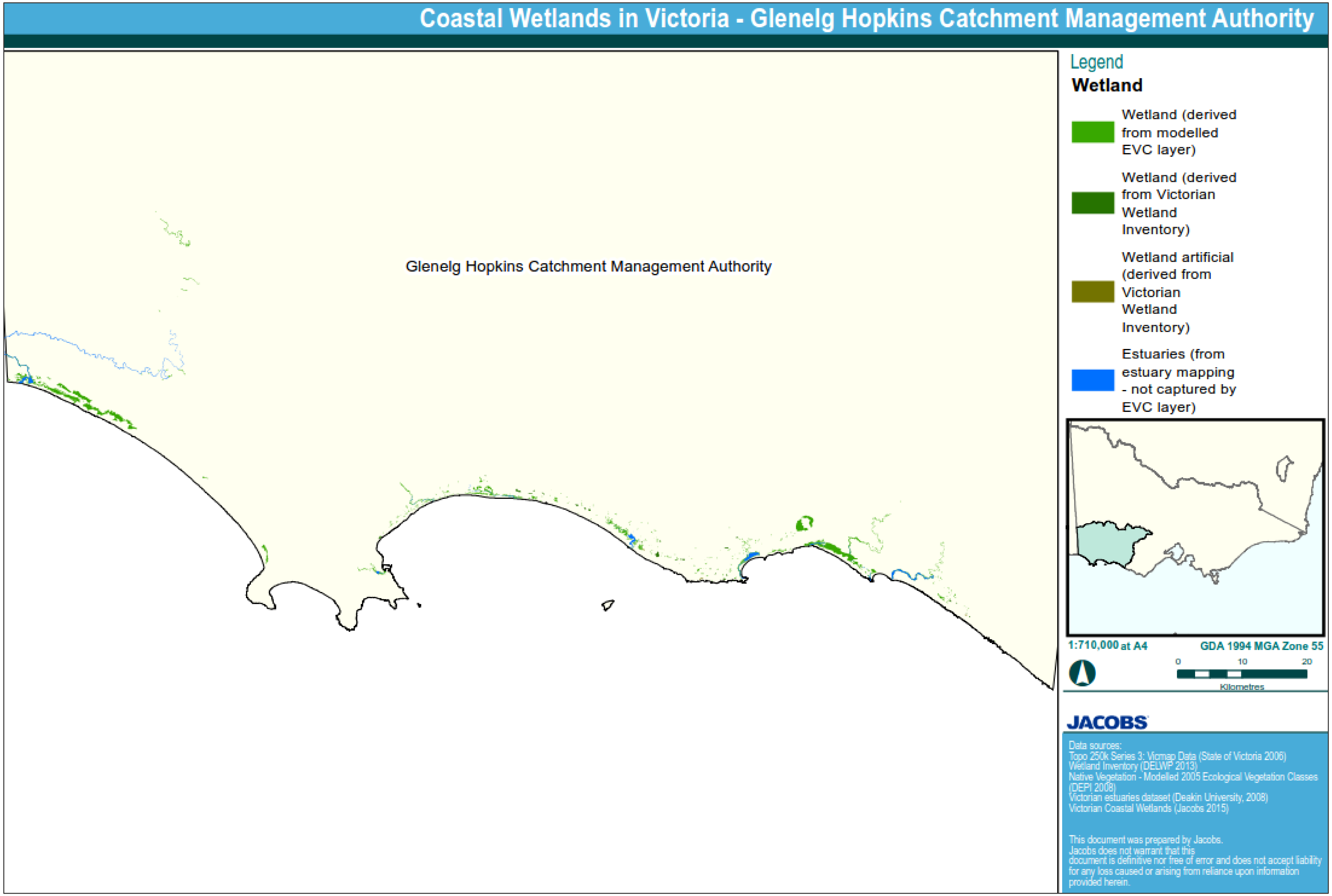


Figure 21: Coastal Wetland Mapping – Glenelg Hopkins Catchment Management Authority (non-wetland EVCs in the 0-10mAHD coastal zone have been excluded in the mapping)

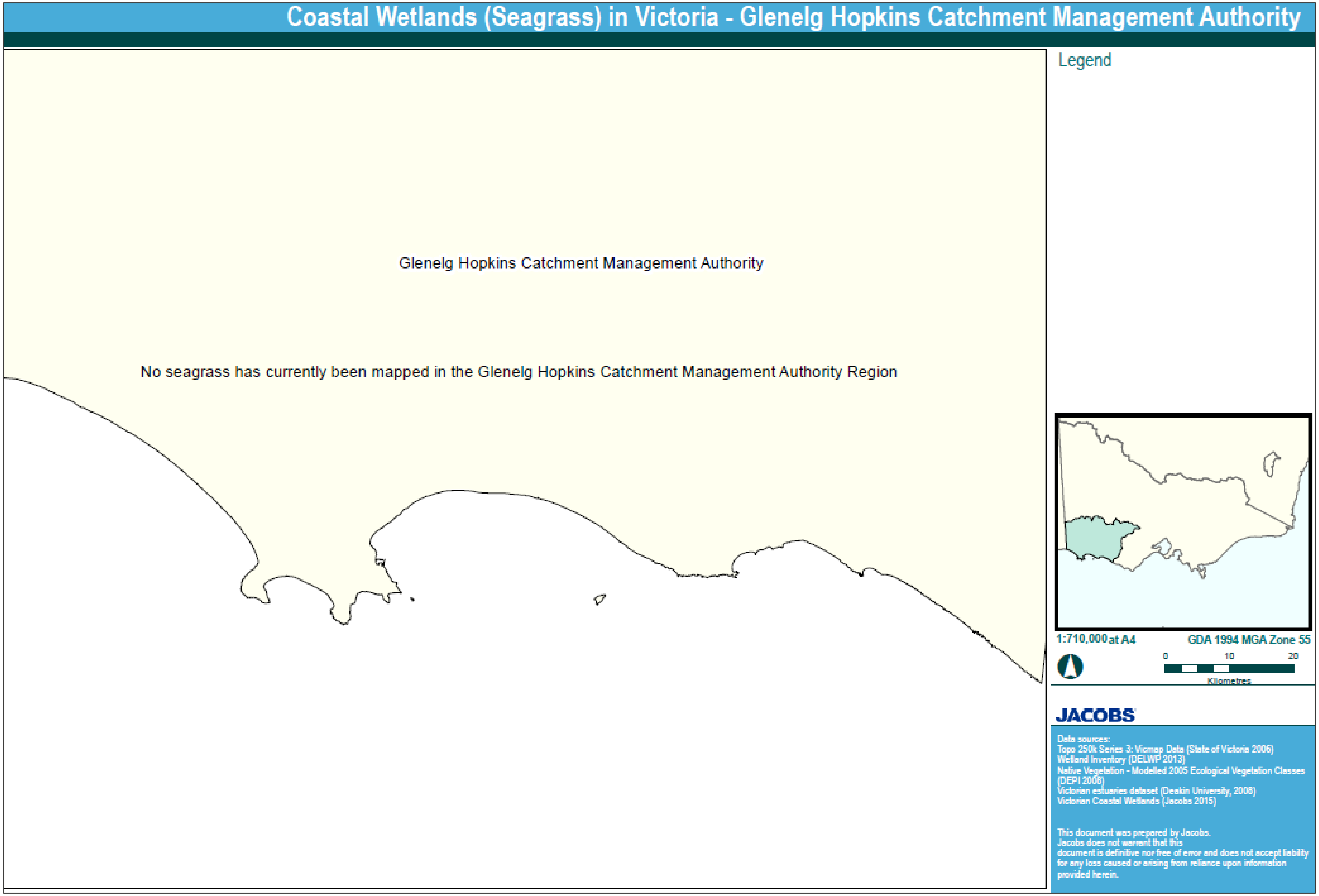


Figure 22: Coastal Wetland Mapping (Seagrass) – Glenelg Hopkins Catchment Management Authority

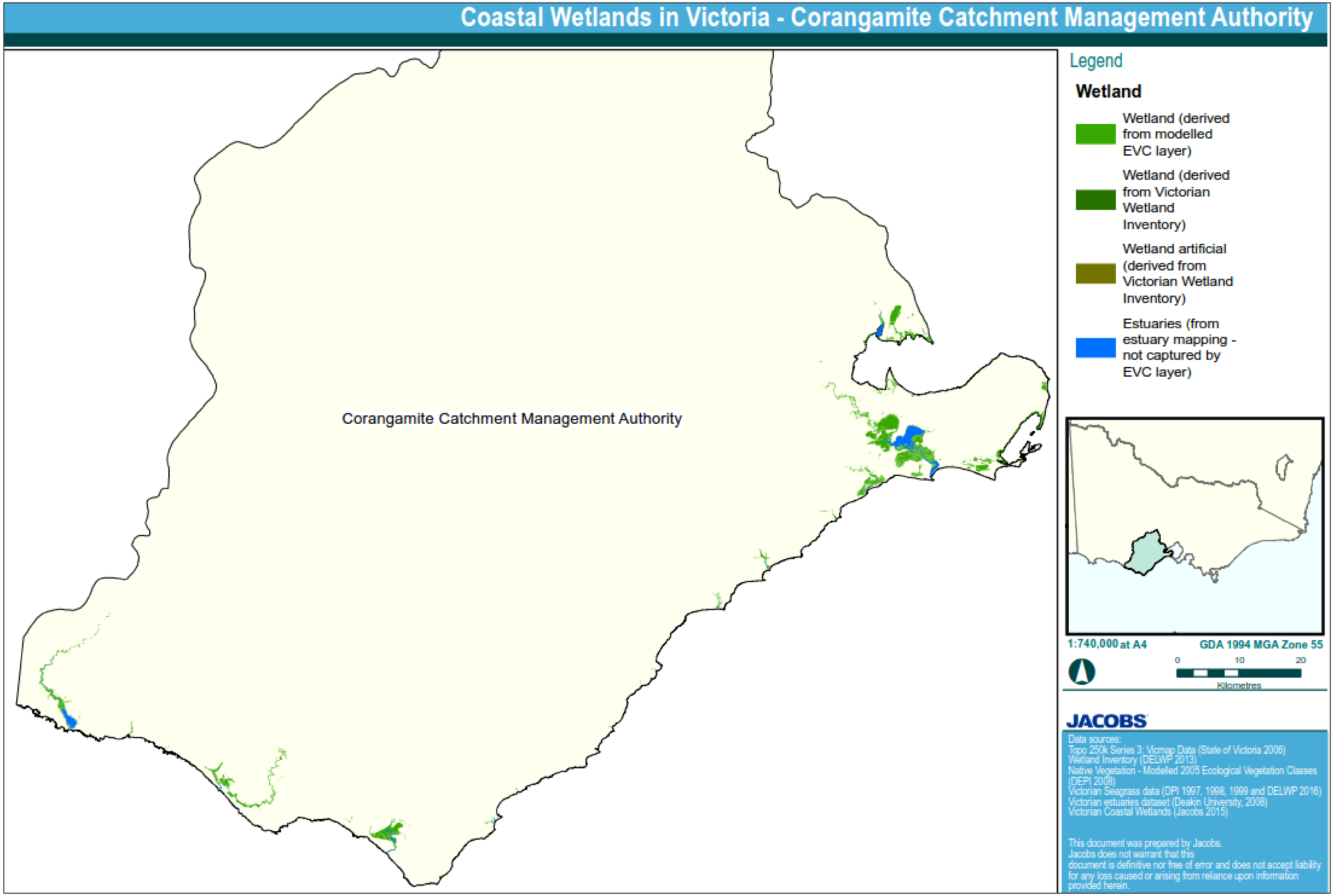


Figure 23: Coastal Wetland Mapping – Corangamite Catchment Management Authority (non-wetland EVCs in the 0-10mAHD coastal zone have been excluded in the mapping)

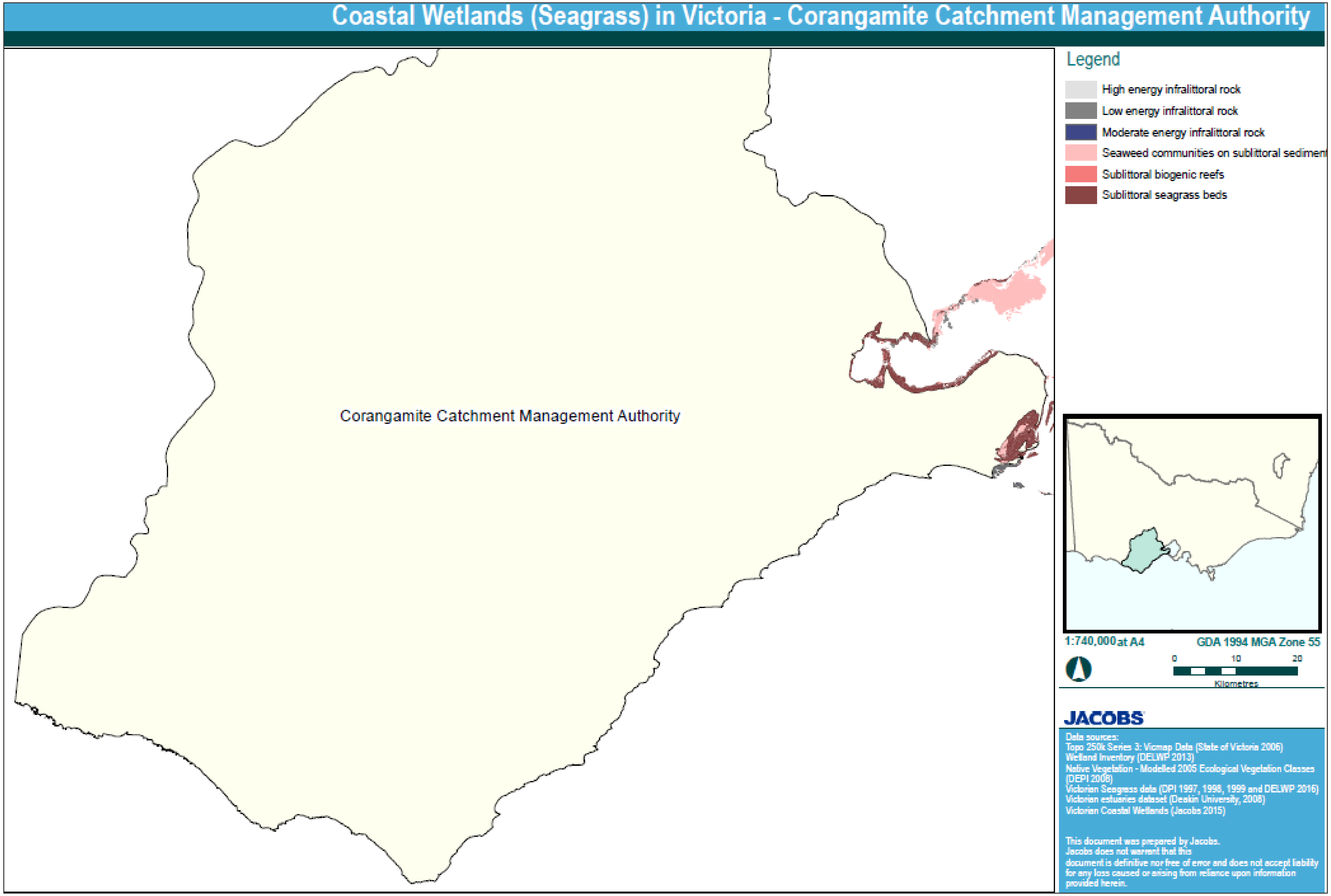


Figure 24: Coastal Wetland Mapping (Seagrass) – Corangamite Catchment Management Authority

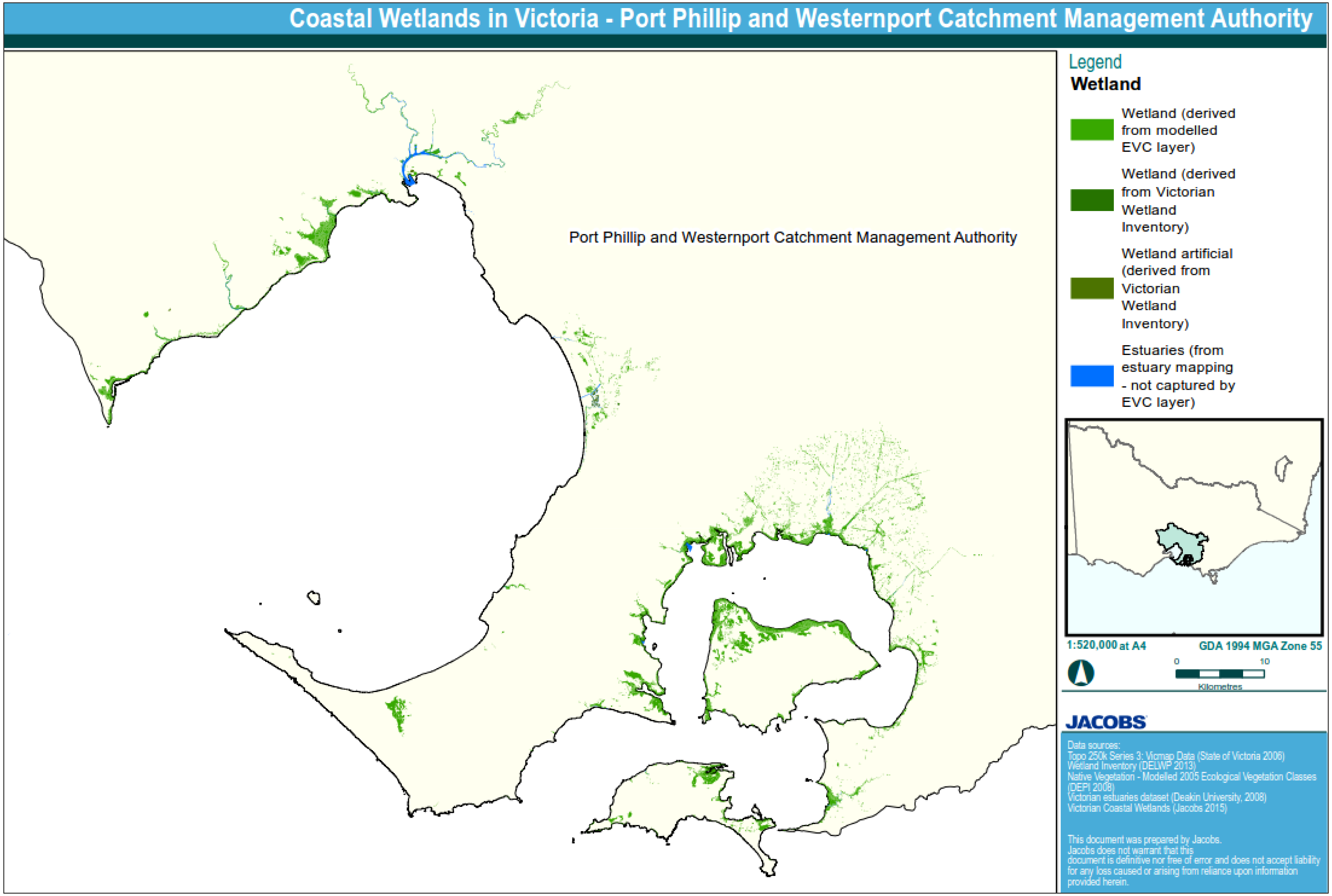


Figure 25: Coastal Wetland (EVCs, wetlands and estuaries) Mapping – Port Phillip and Westernport Catchment Management Authority (non-wetland EVCs in the 0-10mAHD coastal zone have been excluded in the mapping)

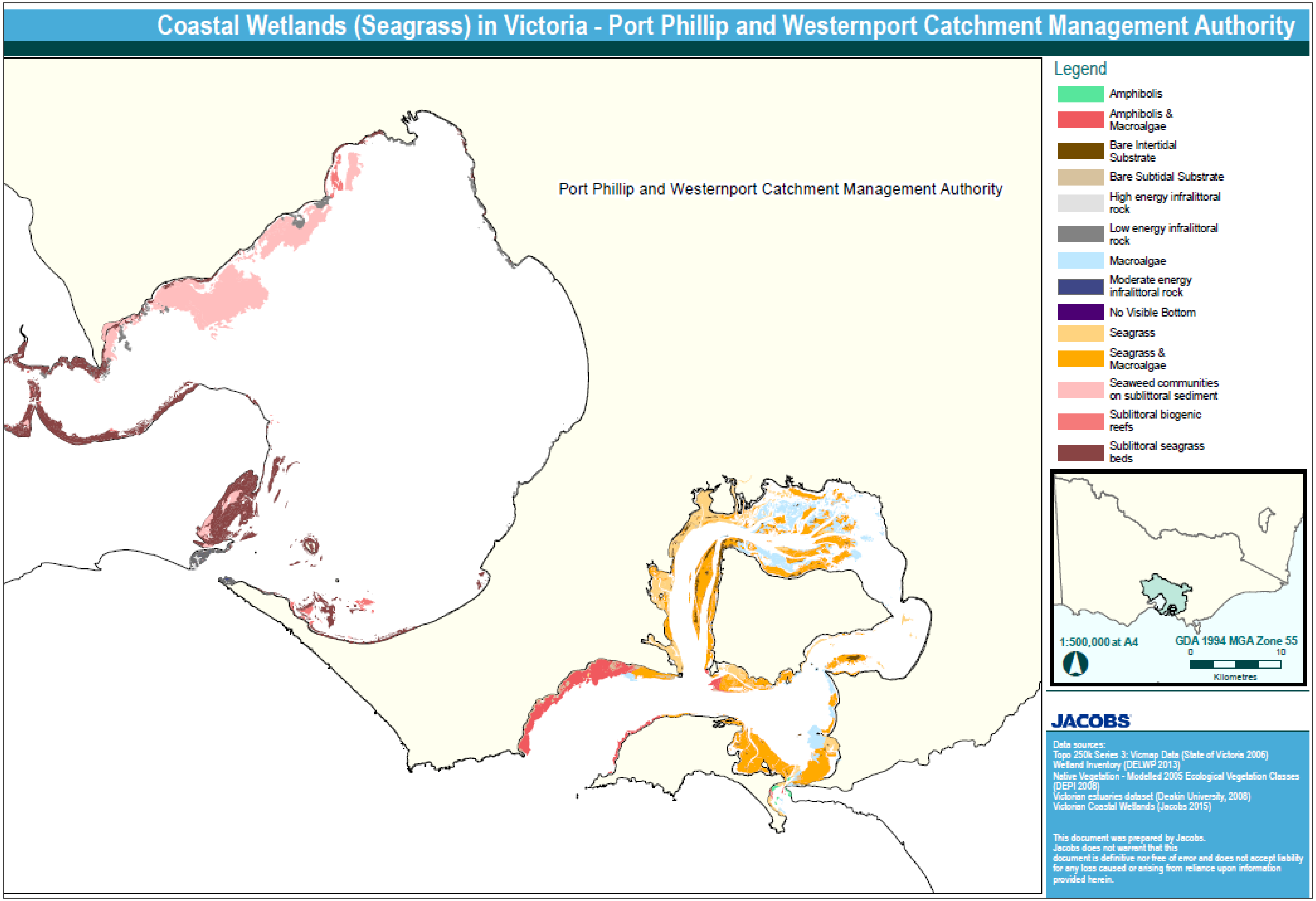


Figure 26: Coastal Wetland Mapping (Seagrass) – Port Phillip and Westernport Catchment Management Authority

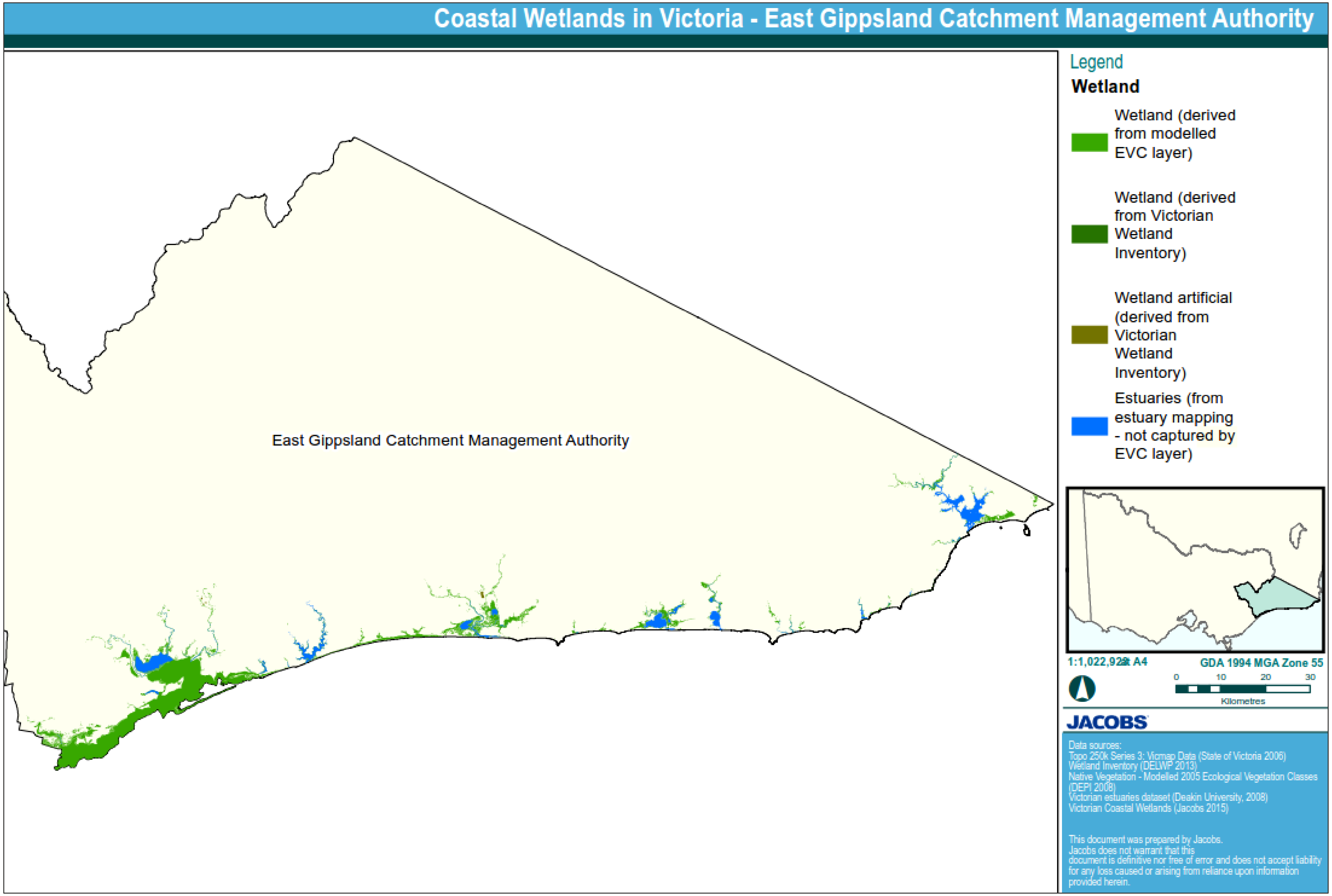


Figure 27: Coastal Wetland Mapping – East Gippsland Catchment Management Authority (non-wetland EVCs in the 0-10mAHD coastal zone have been excluded in the mapping)

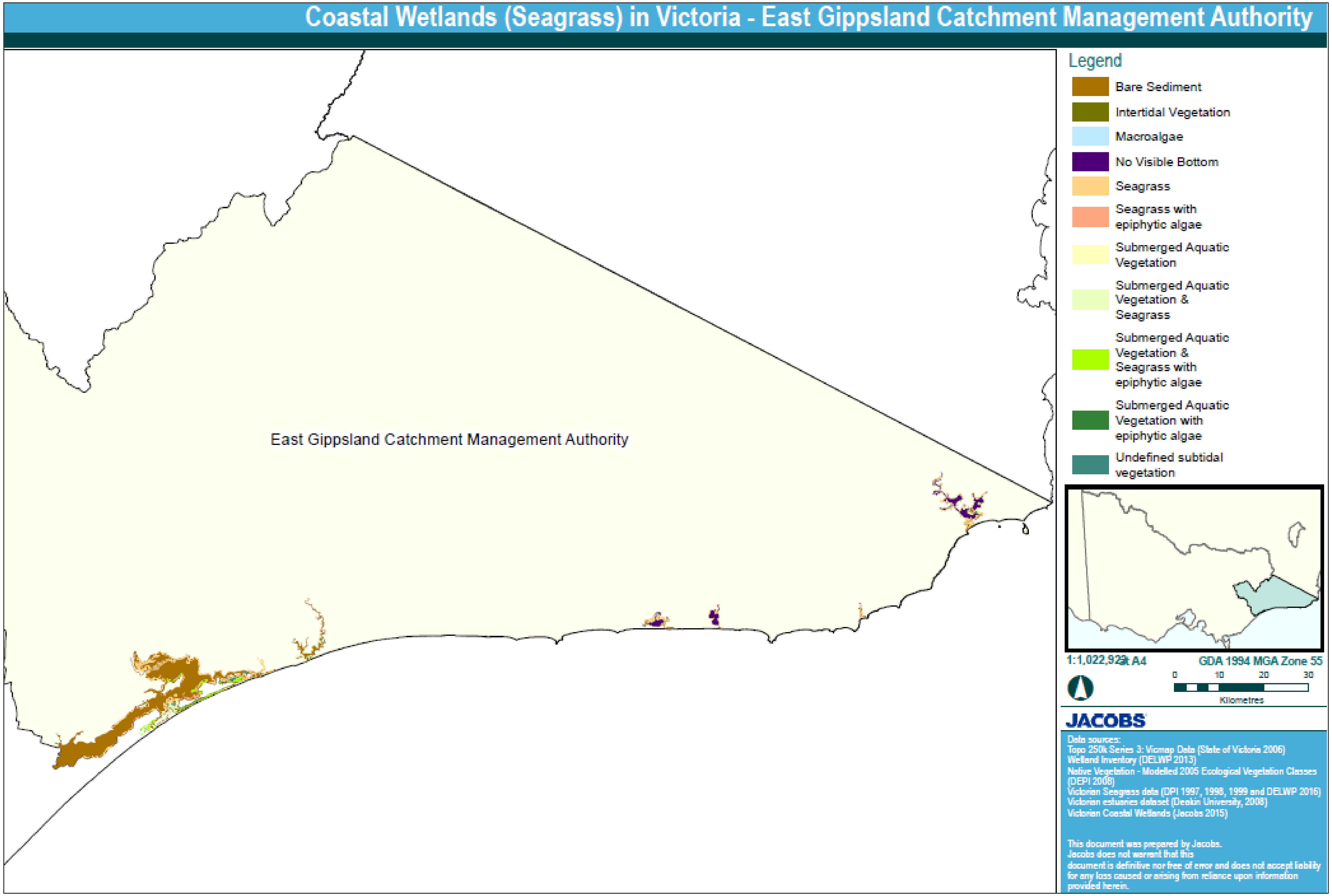


Figure 28: Coastal Wetland Mapping (Seagrass) – East Gippsland Catchment Management Authority

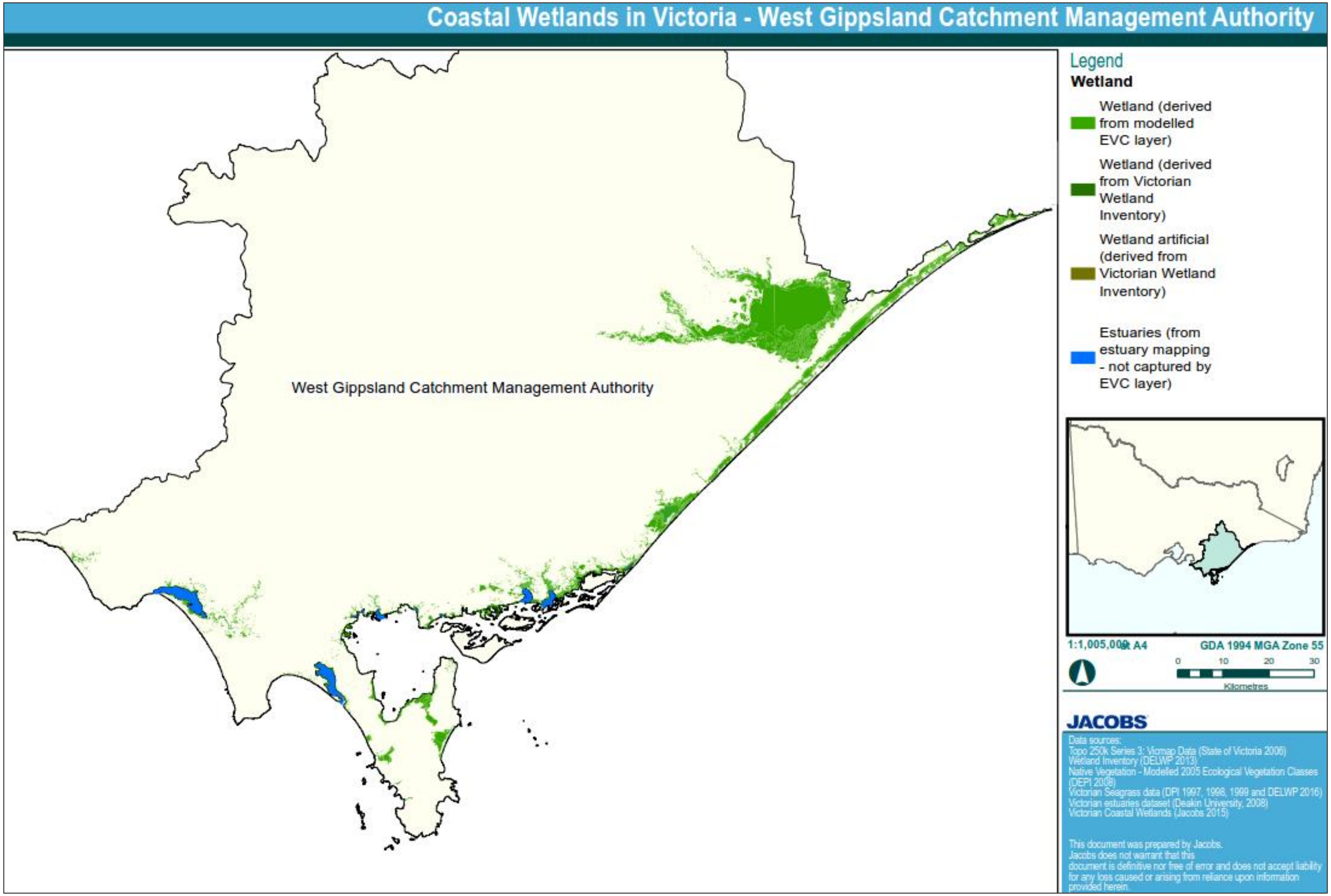


Figure 29: Coastal Wetland Mapping – West Gippsland Catchment Management Authority (non-wetland EVCs in the 0-10mAHD coastal zone have been excluded in the mapping)

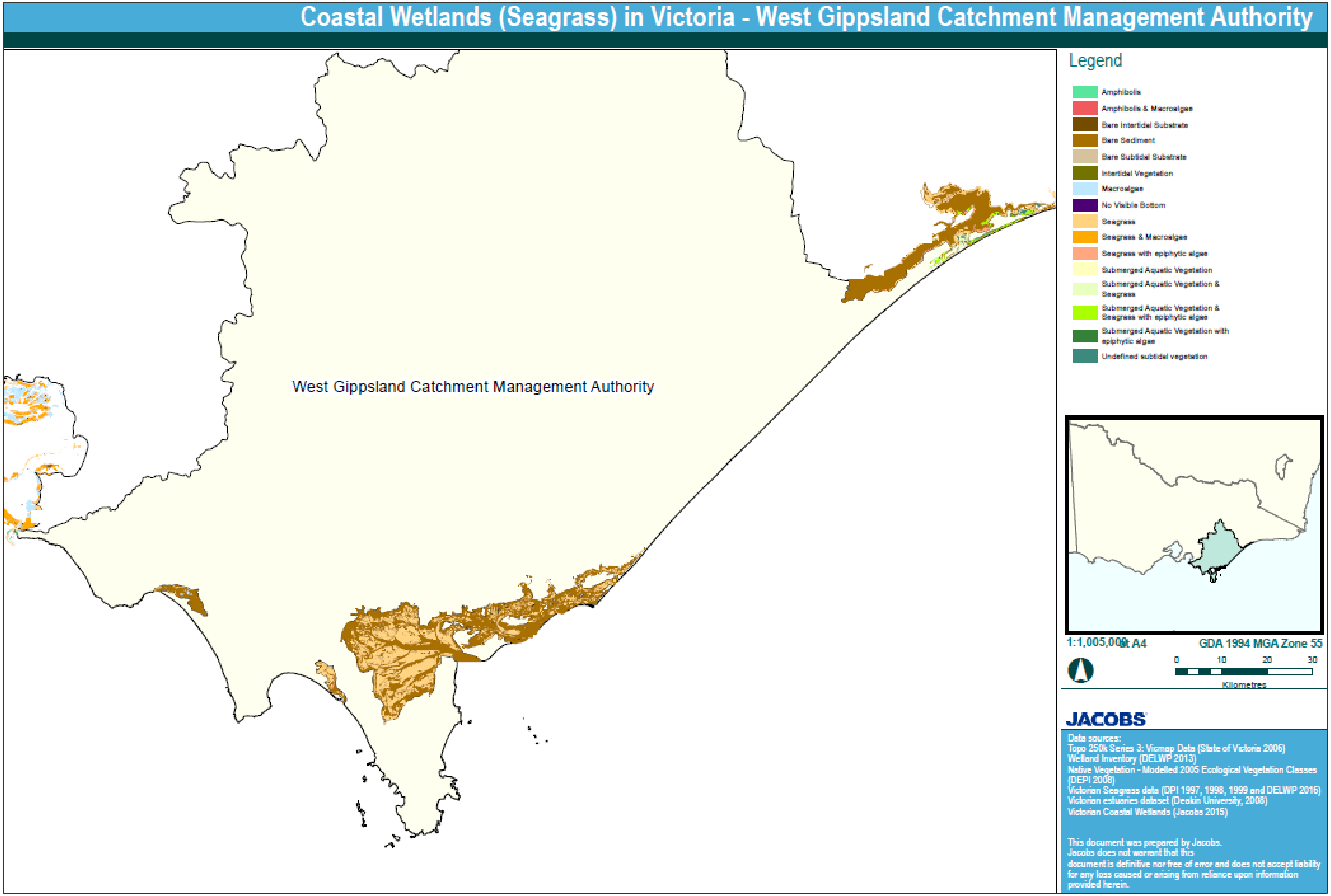


Figure 30: Coastal Wetland Mapping (Seagrass) – West Gippsland Catchment Management Authority

Appendix E. Possible climate change components

This table provides a list of climate change components identified (R. Garnaut 2011, IPCC 2014a, IPCC 2014b) and discussed at the stakeholder workshop (22 July 2015) from which the critical climate change components for coastal wetlands adopted for this project were selected.

Climate change component	Change as a result of climate change
Ocean levels	• Increased eustatic sea level • Increased extreme tides, storm surges and storm tides (coastal flooding) • Increased coastal erosion and shoreline recession • Altered salinity regimes Increased salt water intrusion to groundwater
Carbon Dioxide	• Increased CO_2 concentration • Increased acidification
Rainfall	• Decreased average rainfall • Increased rainfall variability • Change in rainfall distribution during the year • Increased extreme rainfall • Decreased rainfall runoff • Reduction in inflows to waterways and waterbodies/ change in flow regime • Decreased rainfall recharge to groundwater
Temperature	• Increased average air temperature • Increased evaporation • Increased soil temperature • Increased ocean water temperature • Increased inland water temperature • Decreased snow coverage
Severe weather events	• Increased incidence of bushfires • Increased incidence of storm events • Increased incidence of flood events • Increased incidence of drought events • Increased incidence of extreme winds • Increased incidence of heatwaves • Decreased incidence of frosts
Other	• Increased ultraviolet radiation • Increased incidence and occurrences of pests and diseases • Increased sedimentation

Appendix F. Climate change exposure mapping

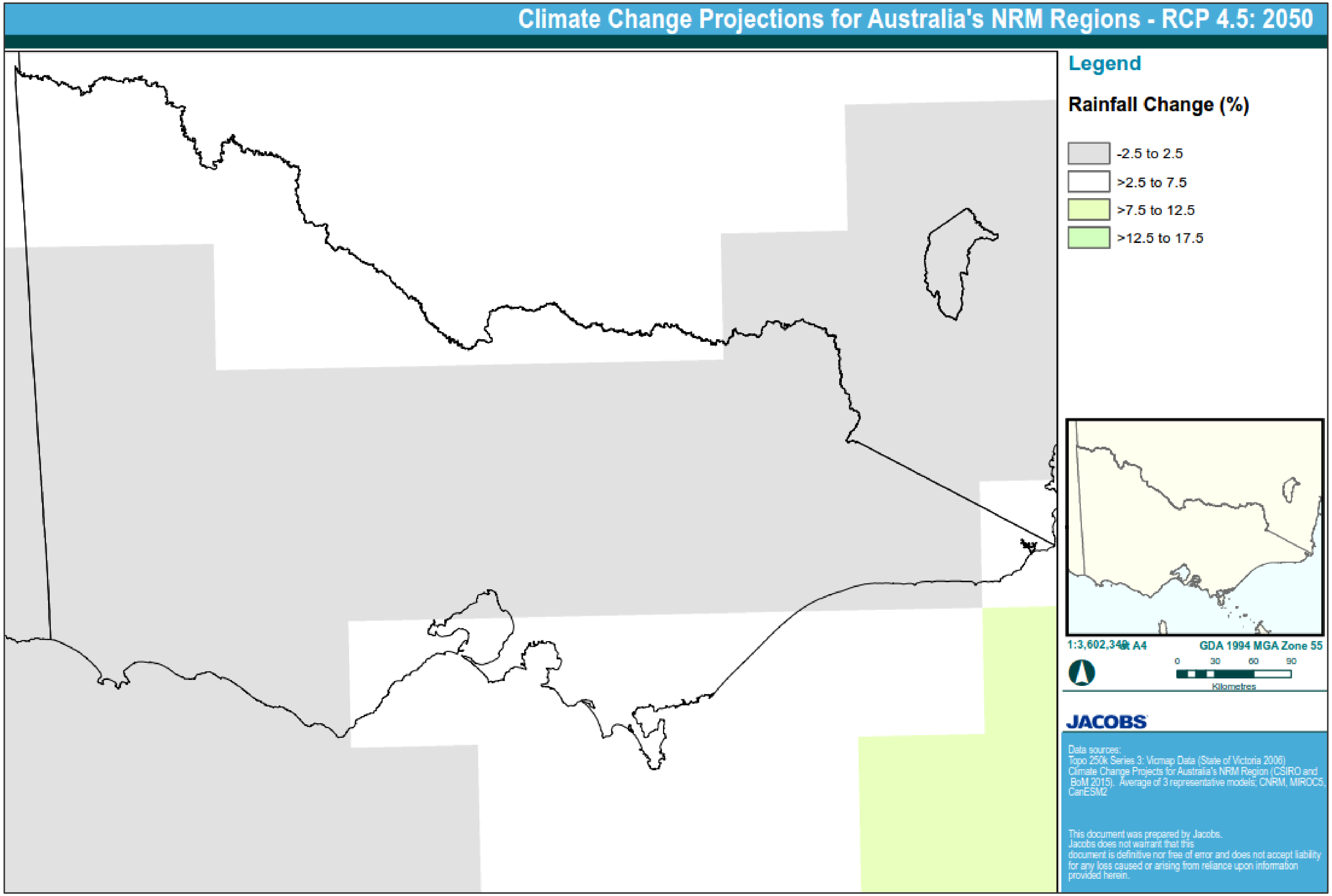


Figure 31: Climate change exposure – change in rainfall RCP 4.5: 2050

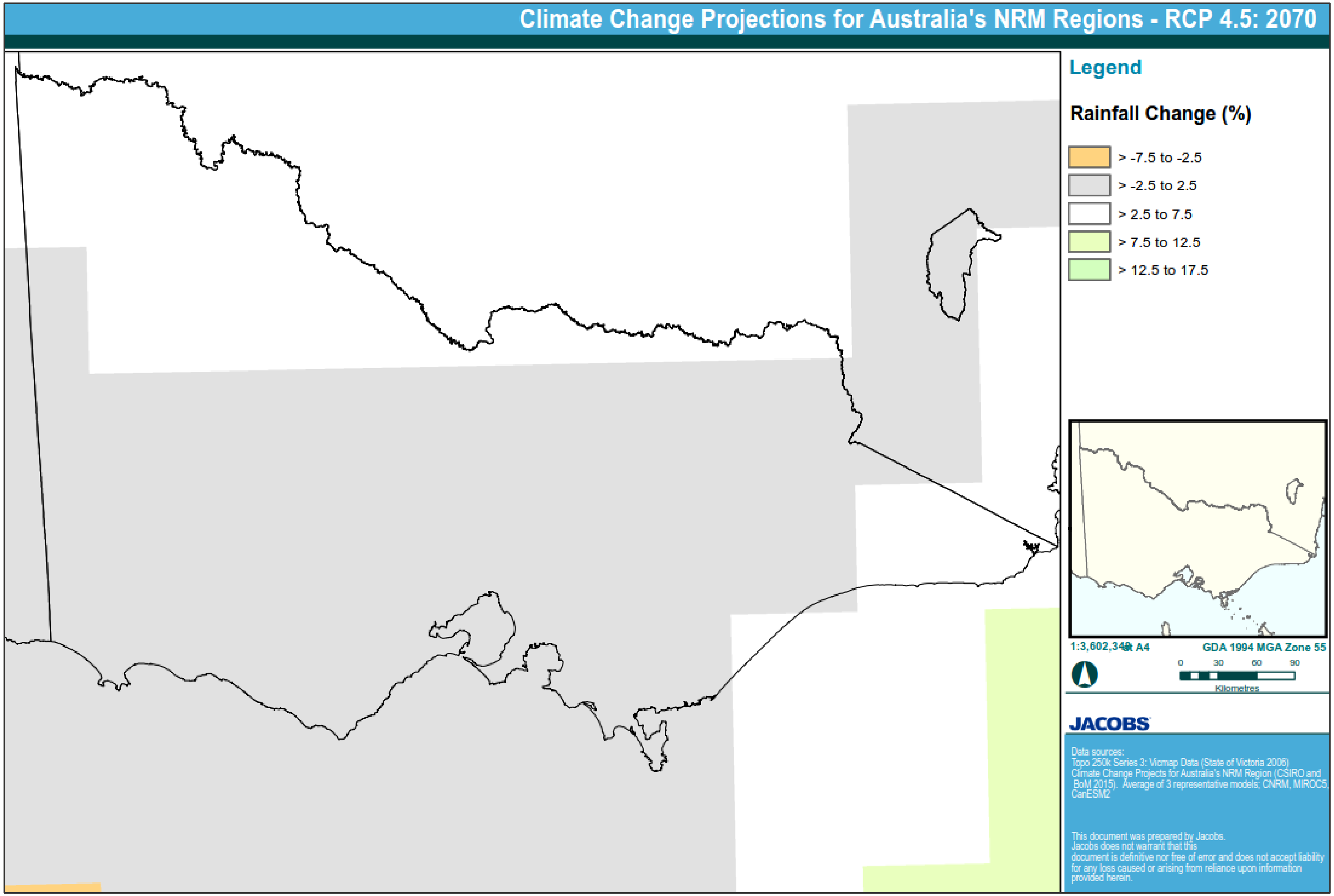


Figure 32: Climate change exposure – change in rainfall RCP 4.5: 2070

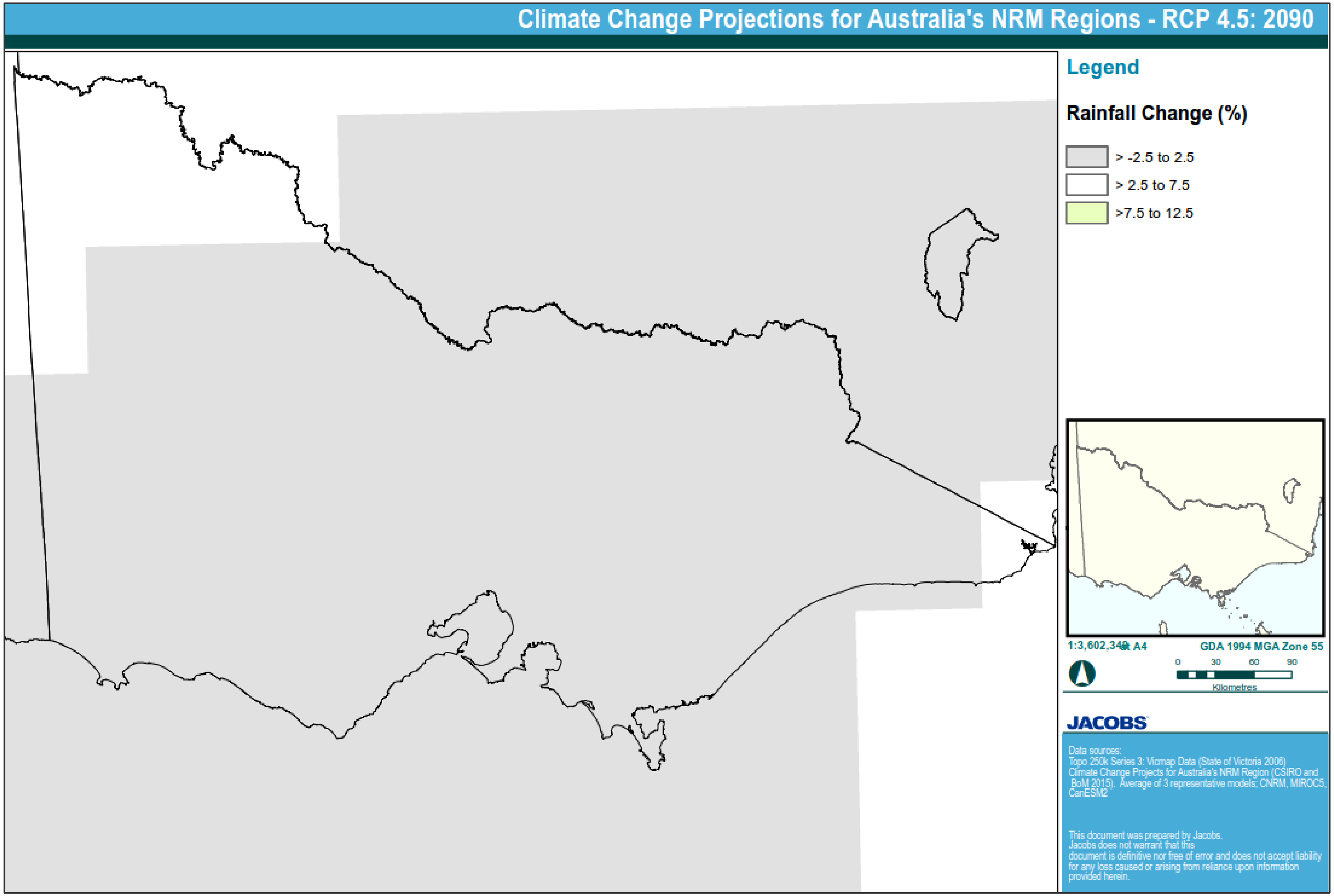


Figure 33: Climate change exposure – change in rainfall RCP 4.5: 2090

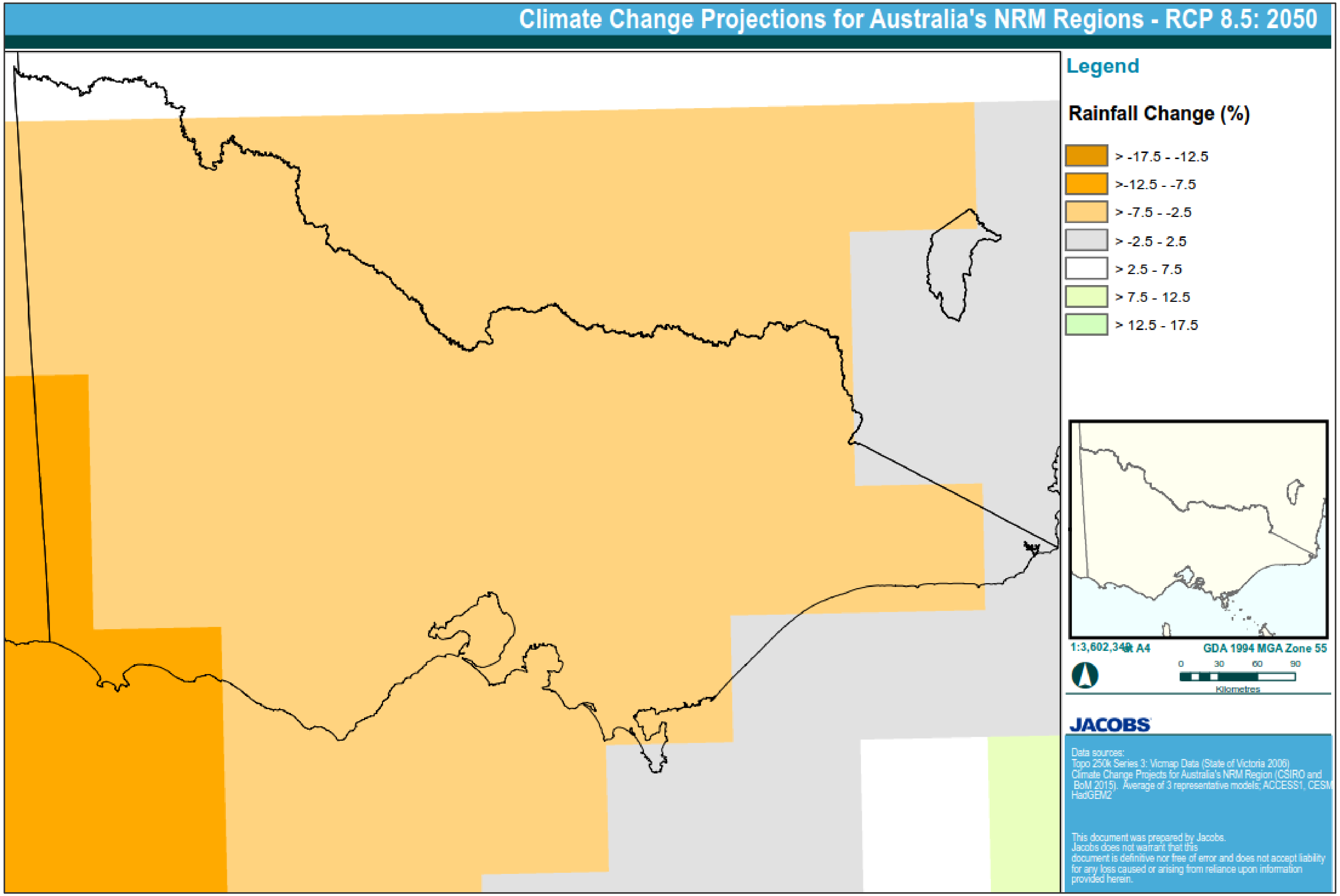


Figure 34: Climate change exposure – change in rainfall RCP 8.5: 2050

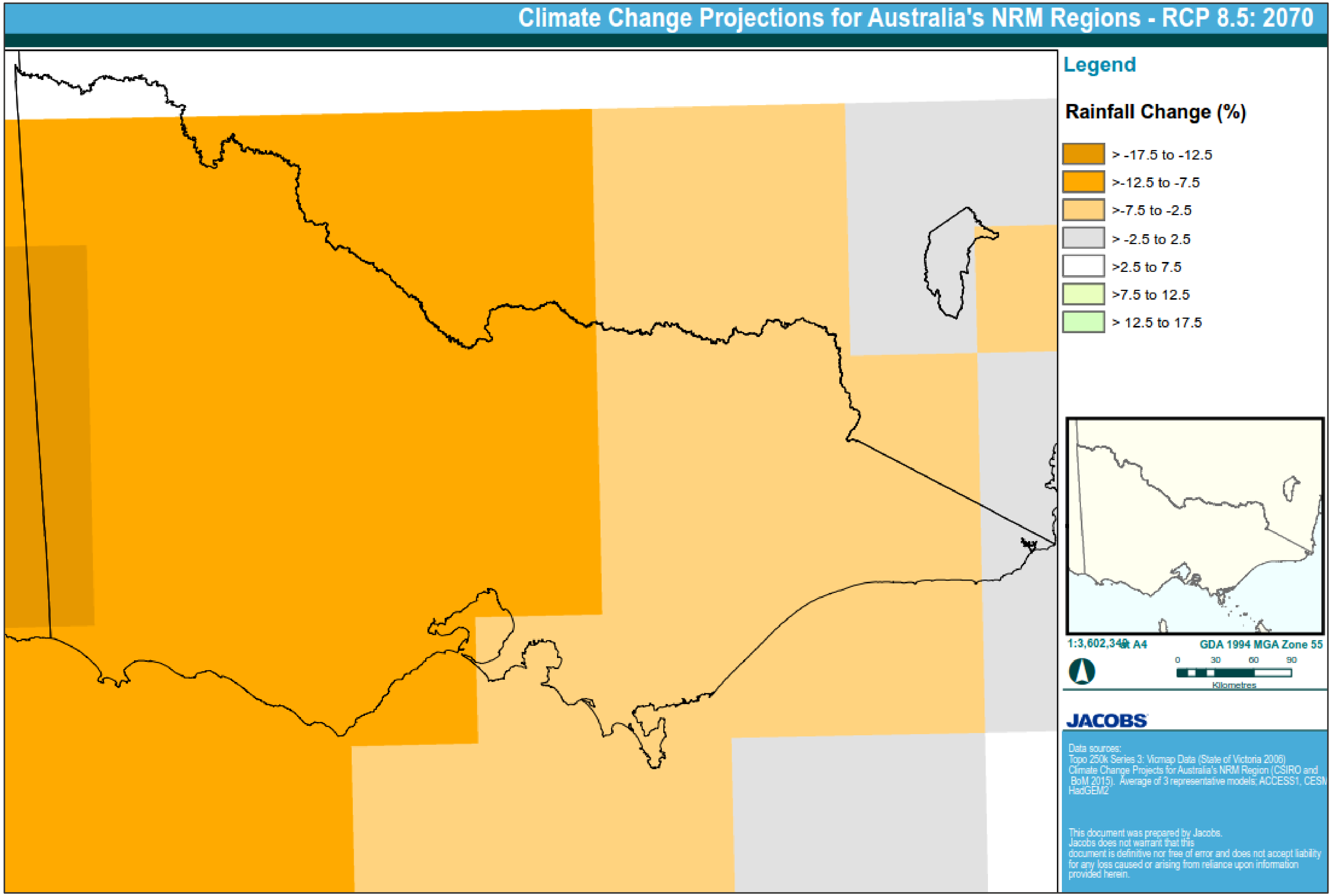


Figure 35: Climate change exposure – change in rainfall RCP 8.5: 2070

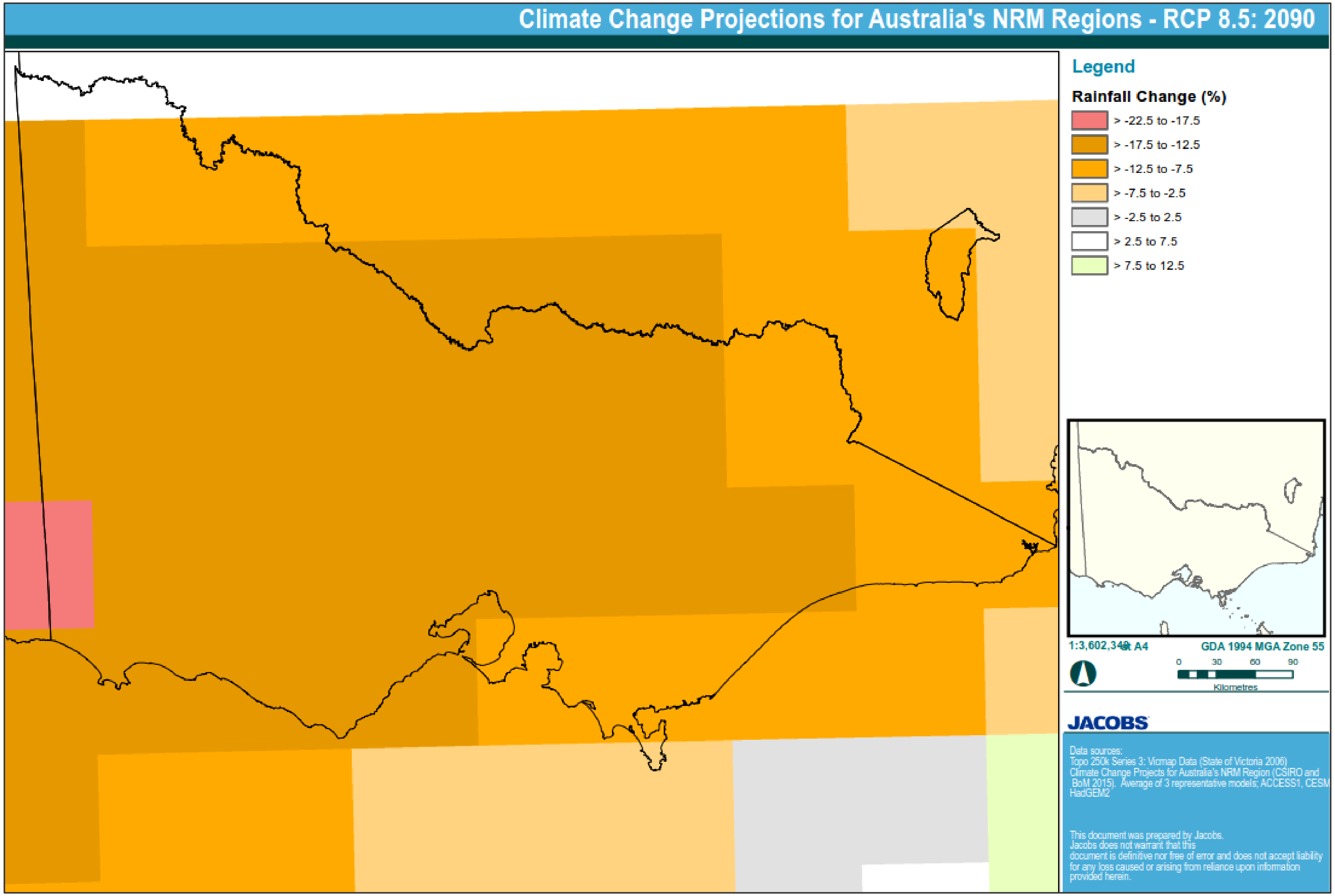


Figure 36: Climate change exposure – change in rainfall RCP 8.5: 2090

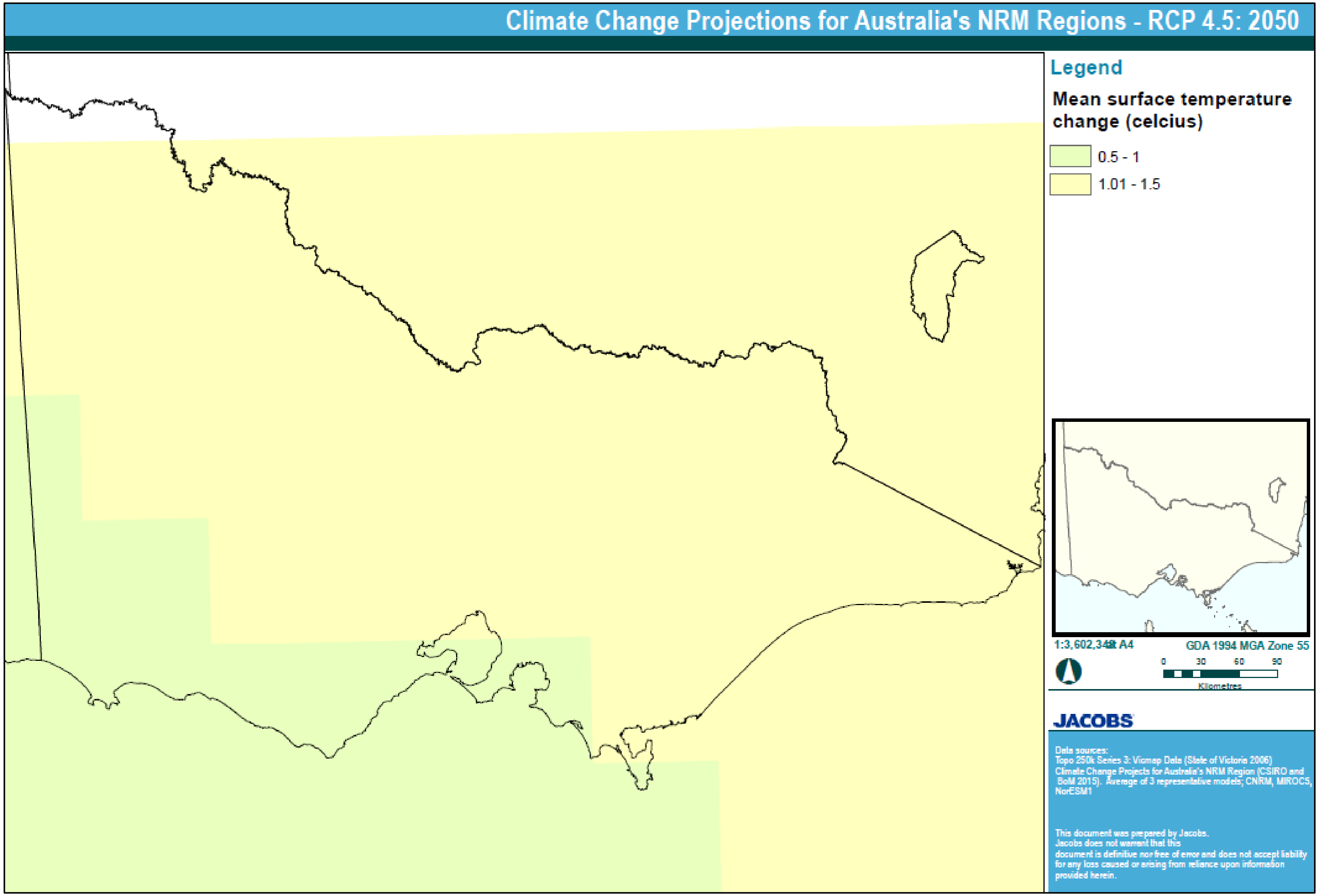


Figure 37: Climate change exposure – change in mean surface temperature RCP 4.5: 2050

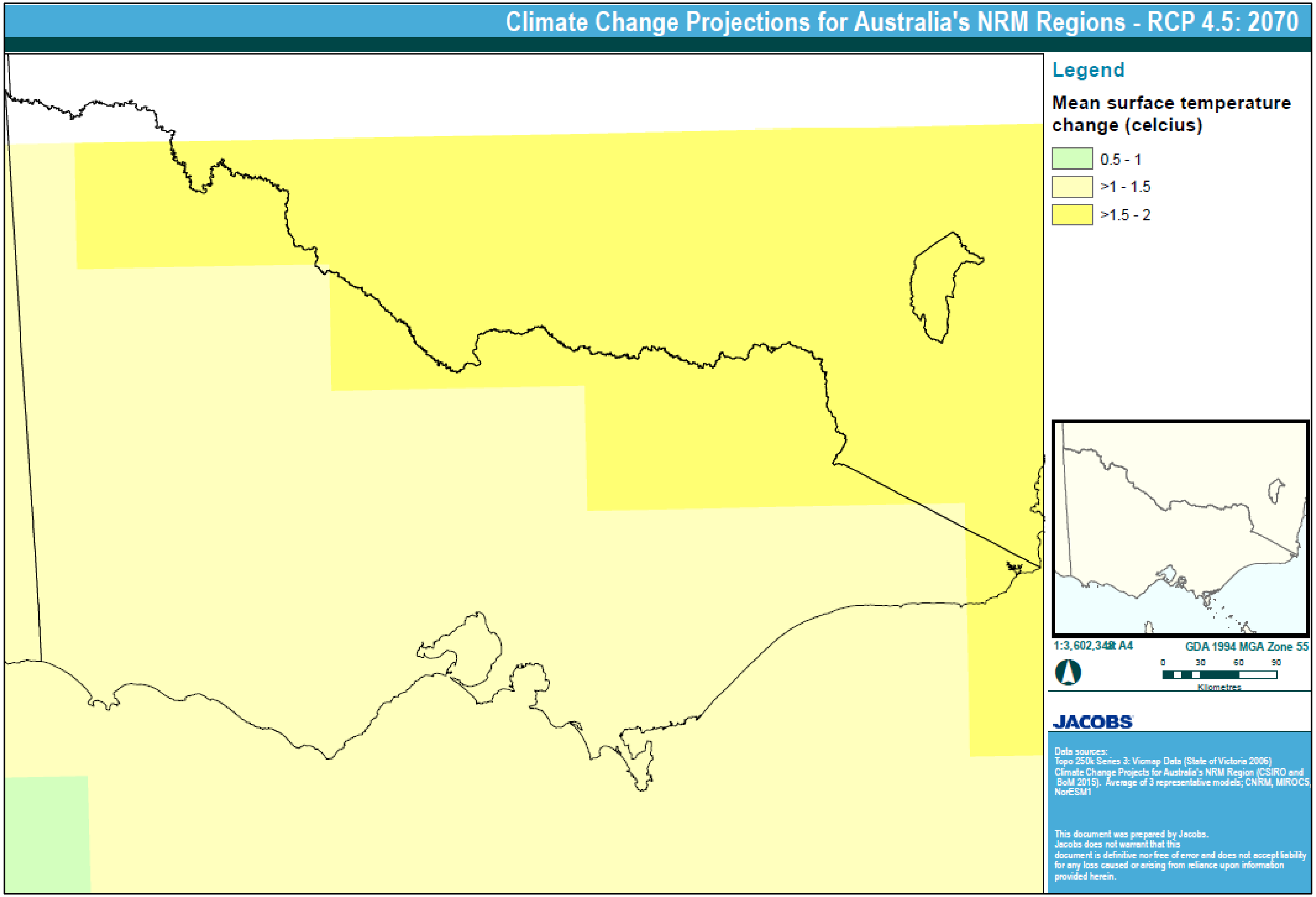


Figure 38: Climate change exposure – change in mean surface temperature RCP 4.5: 2070

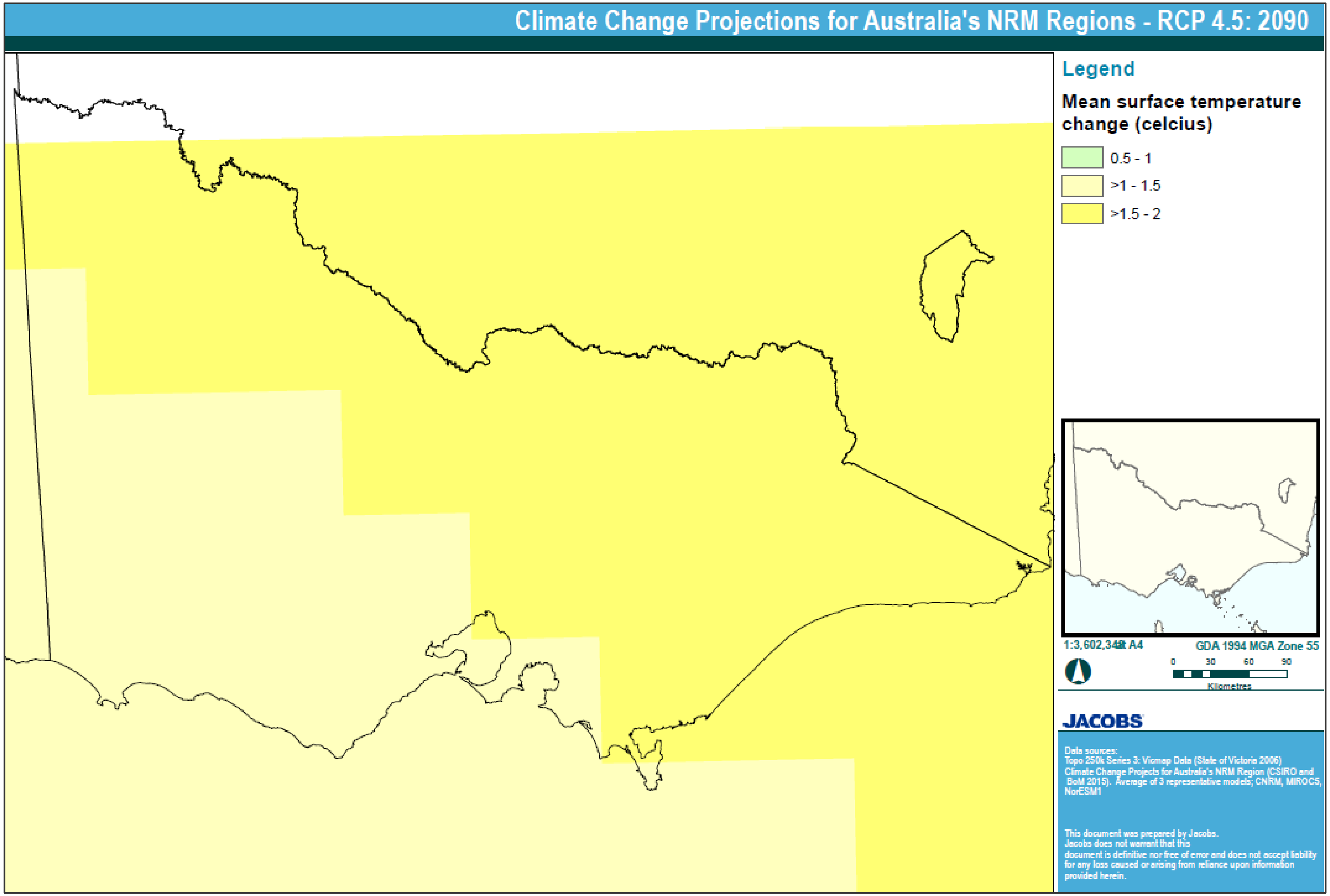


Figure 39: Climate change exposure – change in mean surface temperature RCP 4.5: 2090

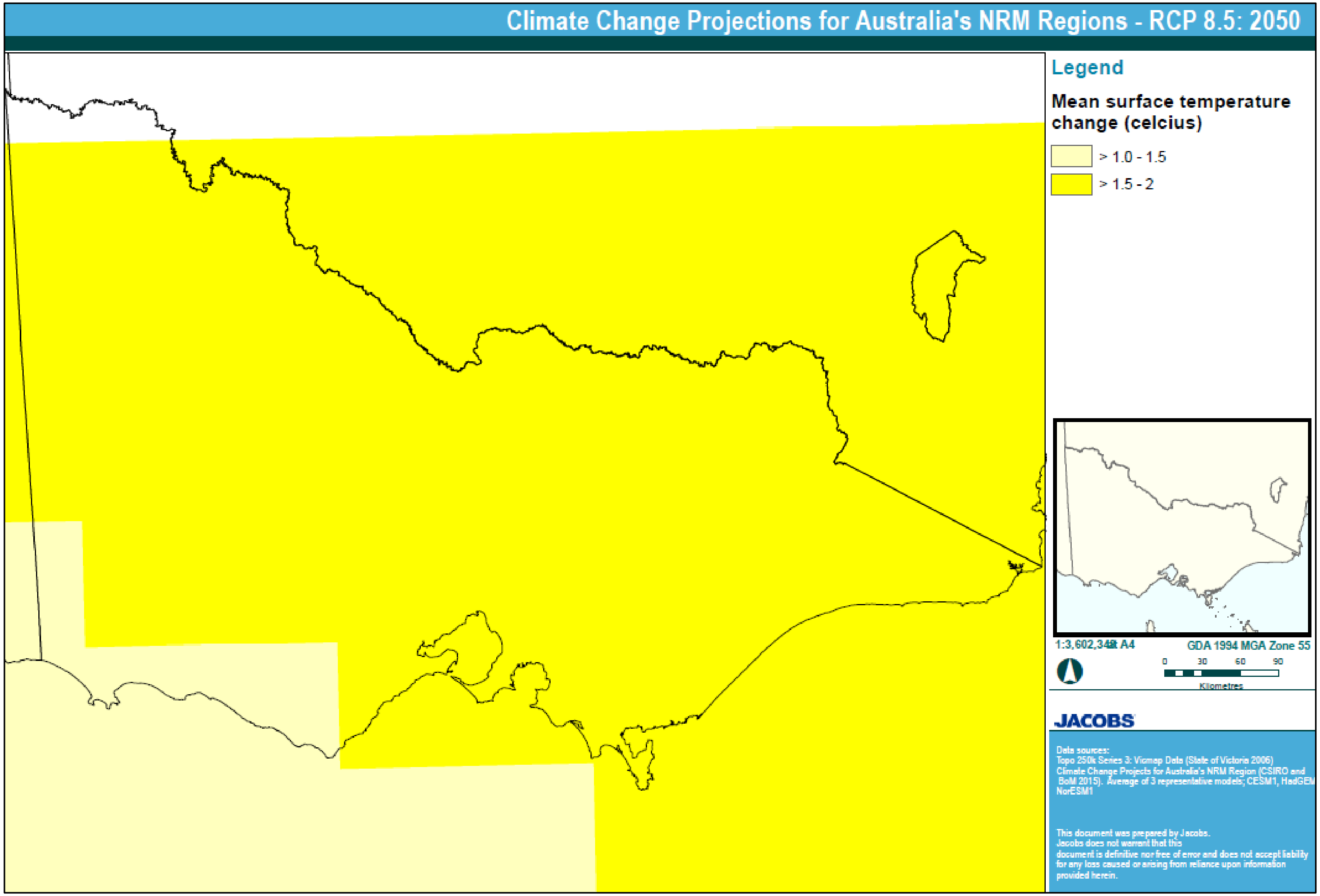


Figure 40: Climate change exposure – change in mean surface temperature RCP 8.5: 2050

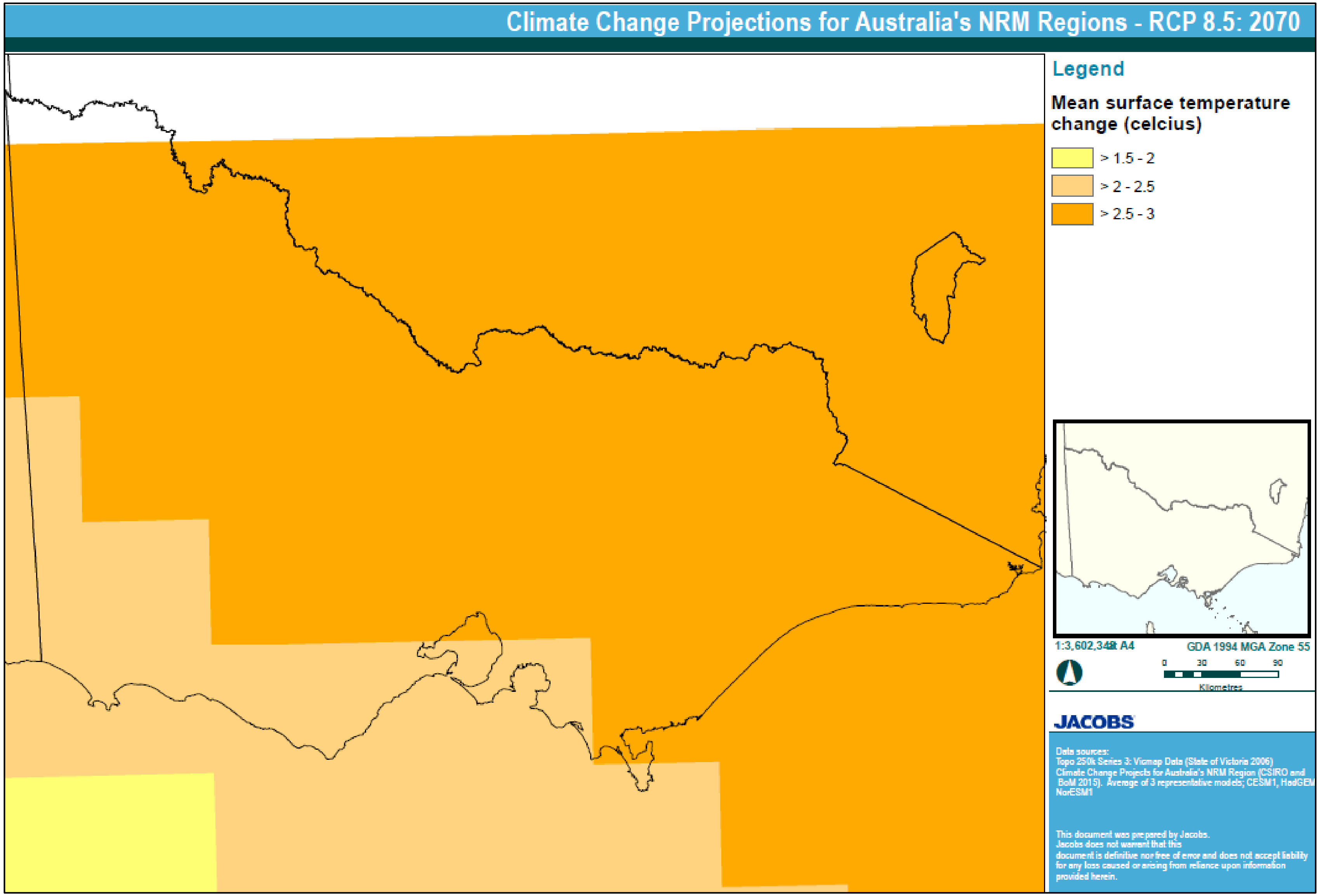


Figure 41: Climate change exposure – change in mean surface temperature RCP 8.5: 2070

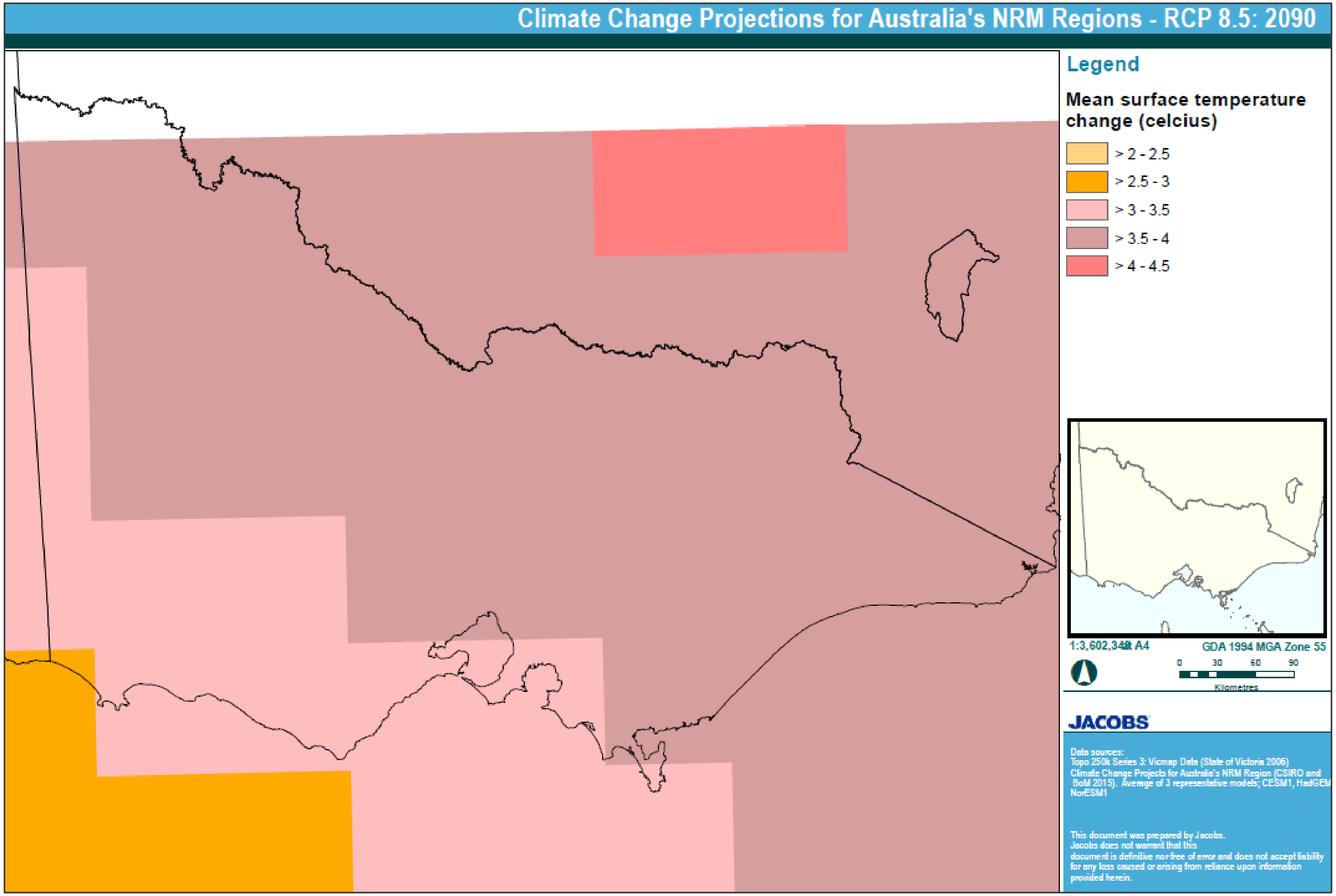


Figure 42: Climate change exposure – change in mean surface temperature RCP 8.5: 2090

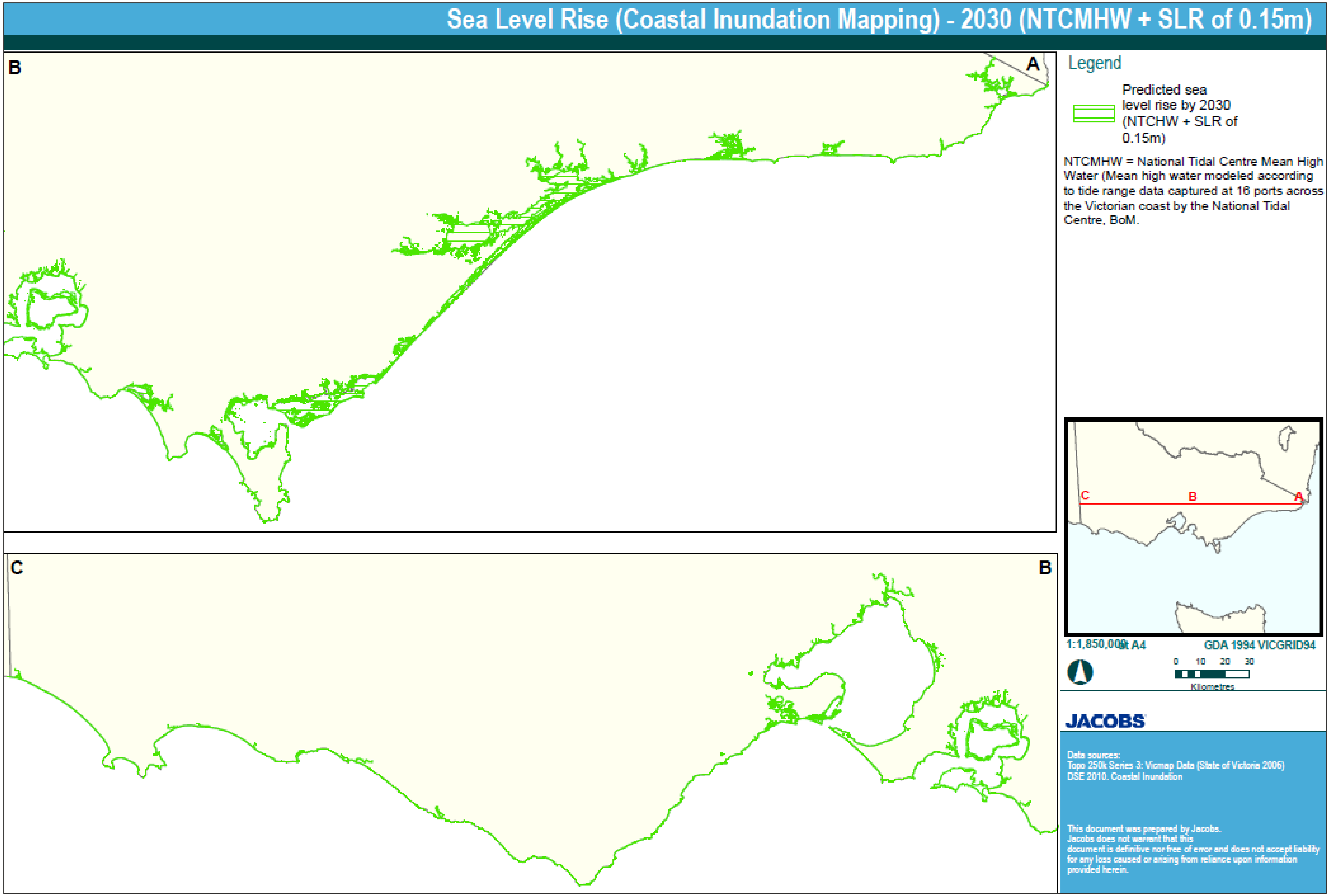


Figure 43: Climate change exposure – Sea level rise: 2030 (DSE 2010, Victorian Coastal Inundation spatial dataset is available to download at https://www.data.vic.gov.au/)

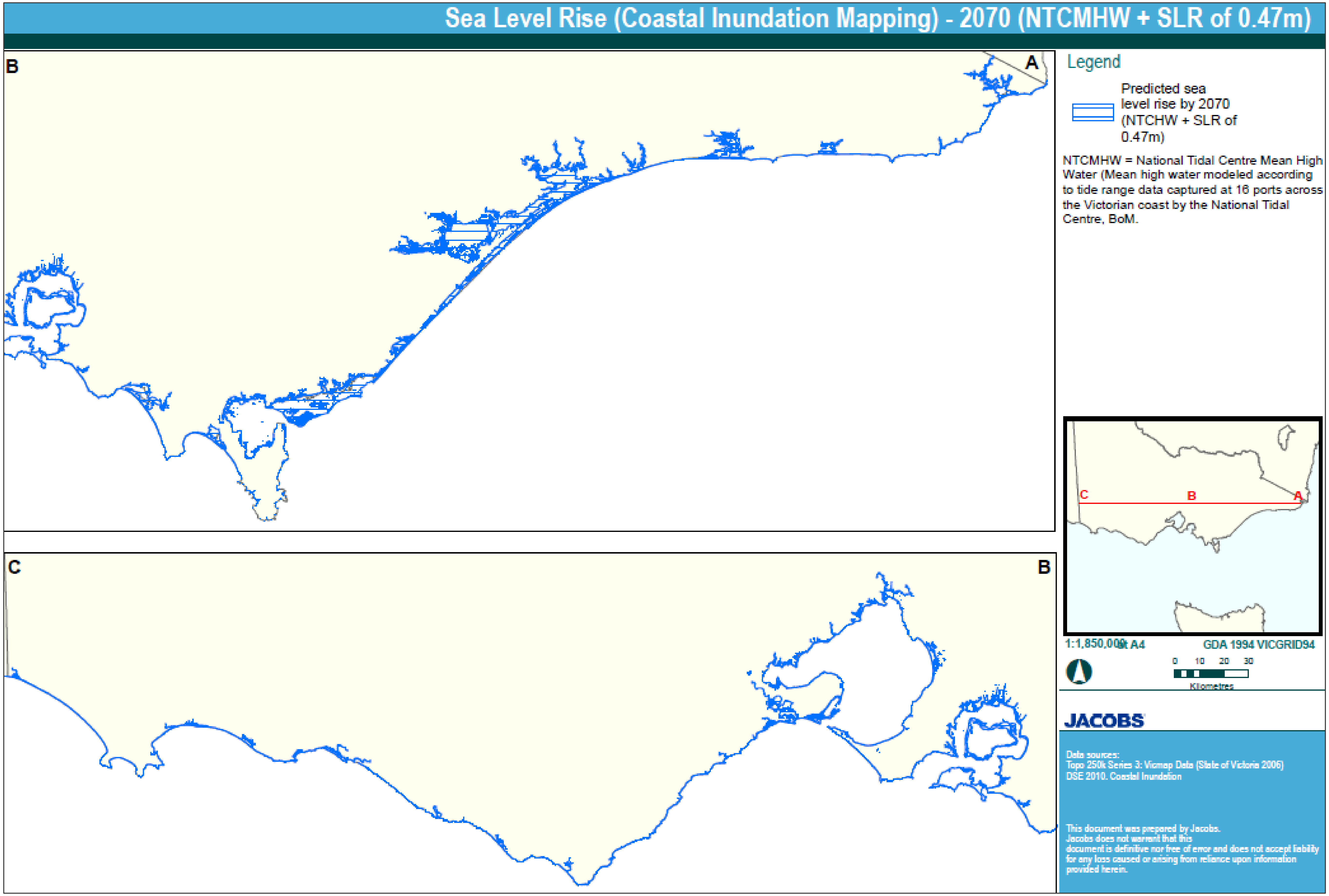


Figure 44: Climate change exposure – Sea level rise: 2070 (DSE 2010, Victorian Coastal Inundation spatial dataset is available to download at https://www.data.vic.gov.au/)

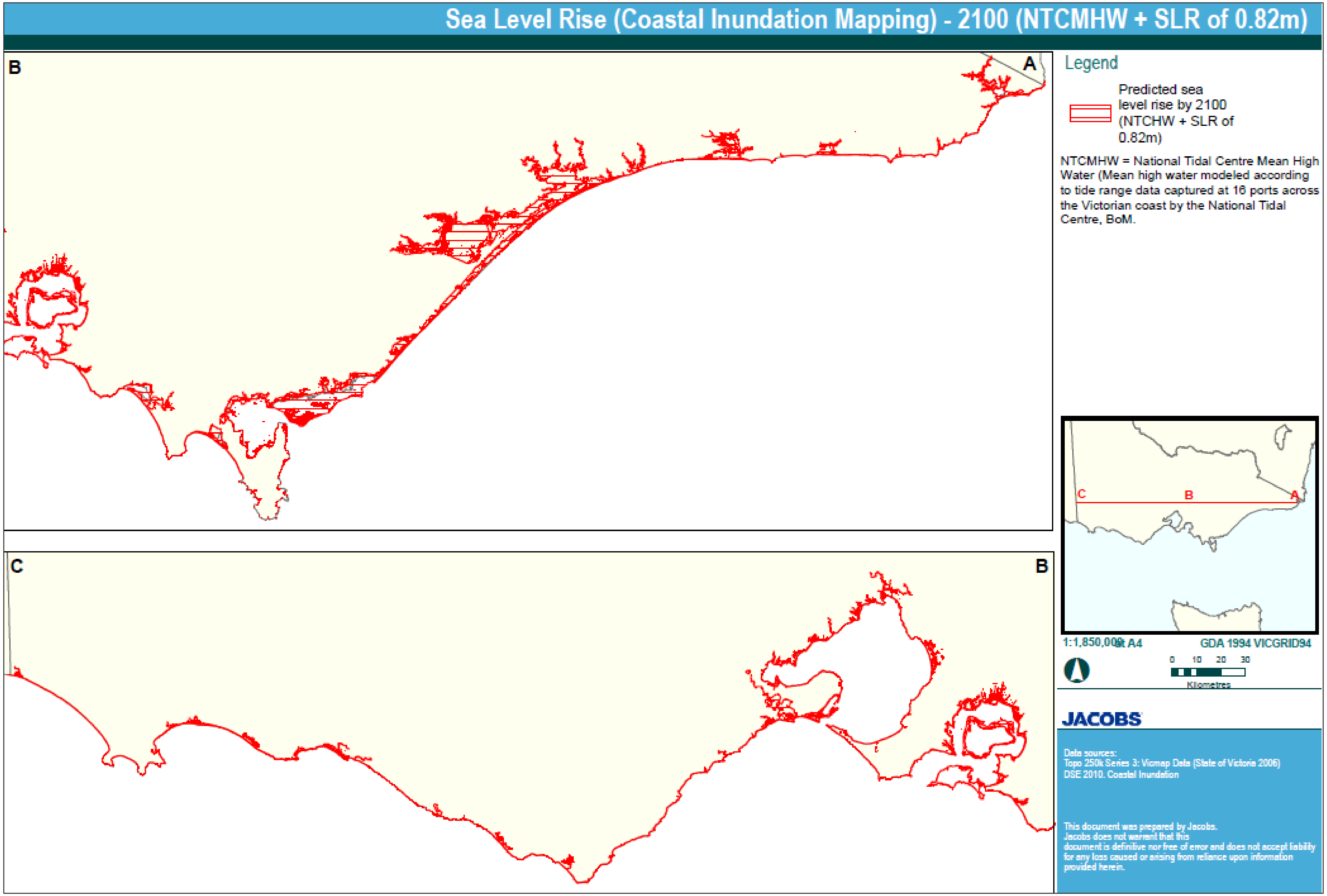


Figure 45: Climate change exposure – Sea level rise: 2100 (DSE 2010, Victorian Coastal Inundation spatial dataset is available to download at https://www.data.vic.gov.au/)

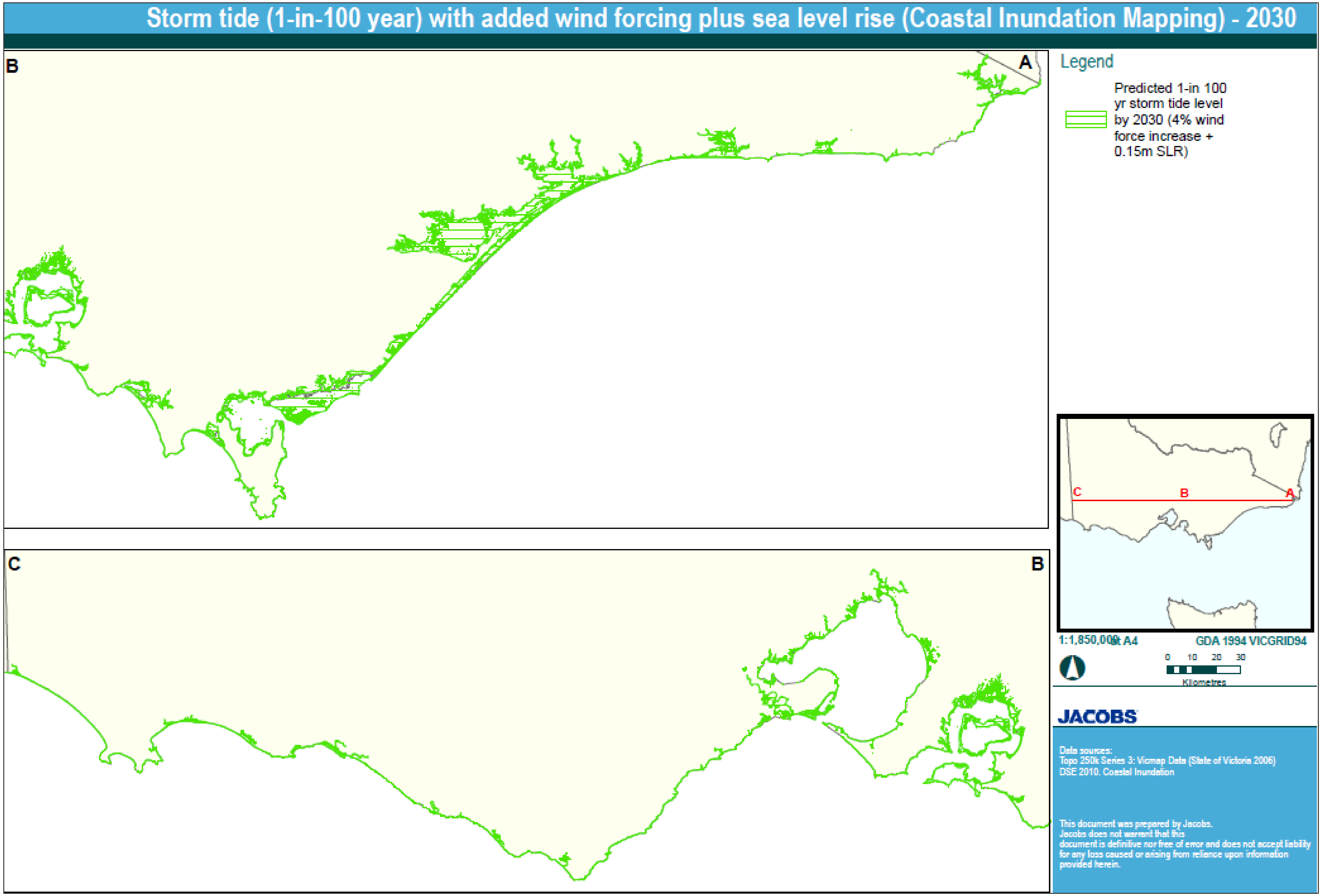


Figure 46: Climate change exposure – Storm tide: 2030 (DSE 2010, Victorian Coastal Inundation spatial dataset is available to download at https://www.data.vic.gov.au/)

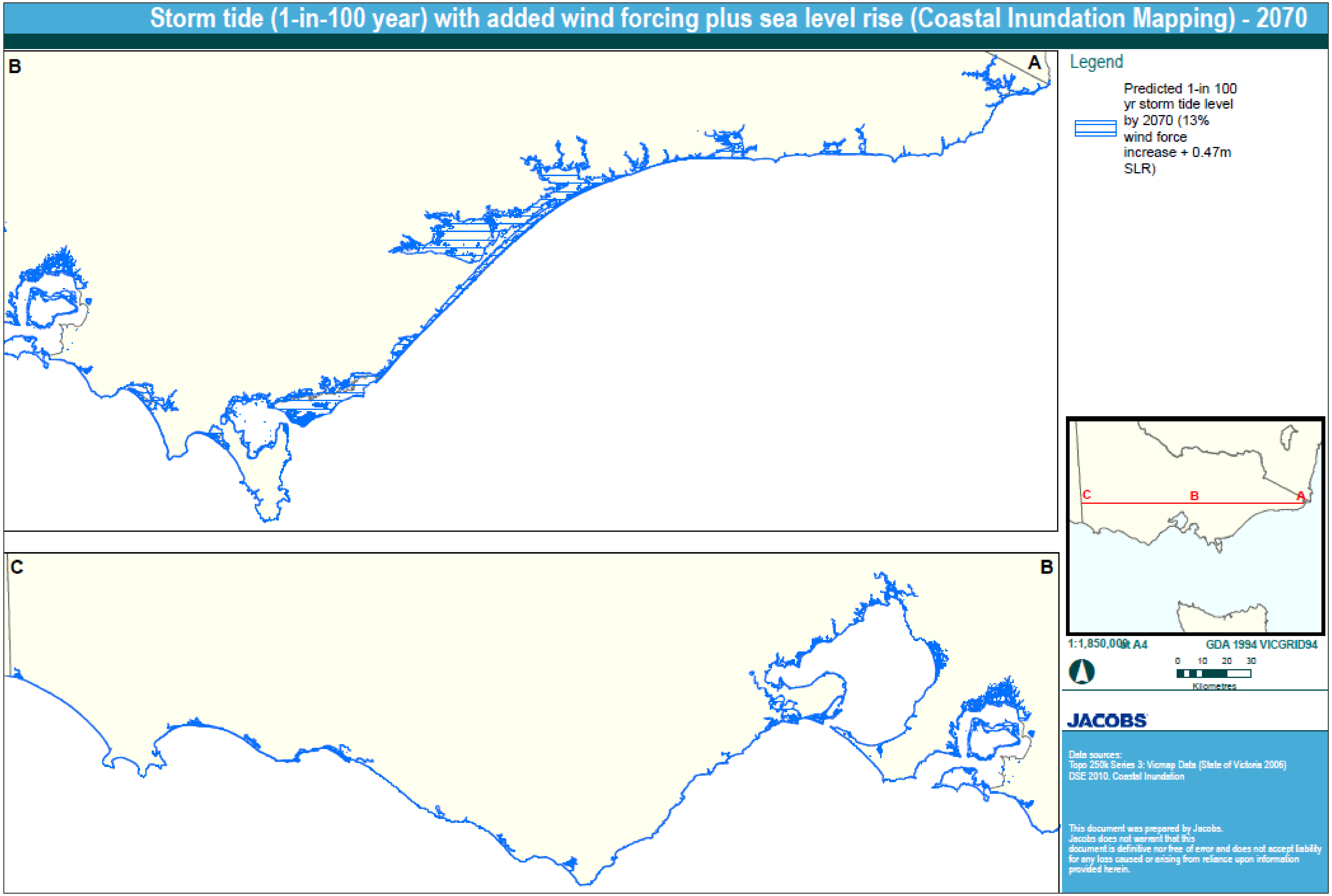


Figure 47: Climate change exposure – Storm tide: 2070 (DSE 2010, Victorian Coastal Inundation spatial dataset is available to download at https://www.data.vic.gov.au/)

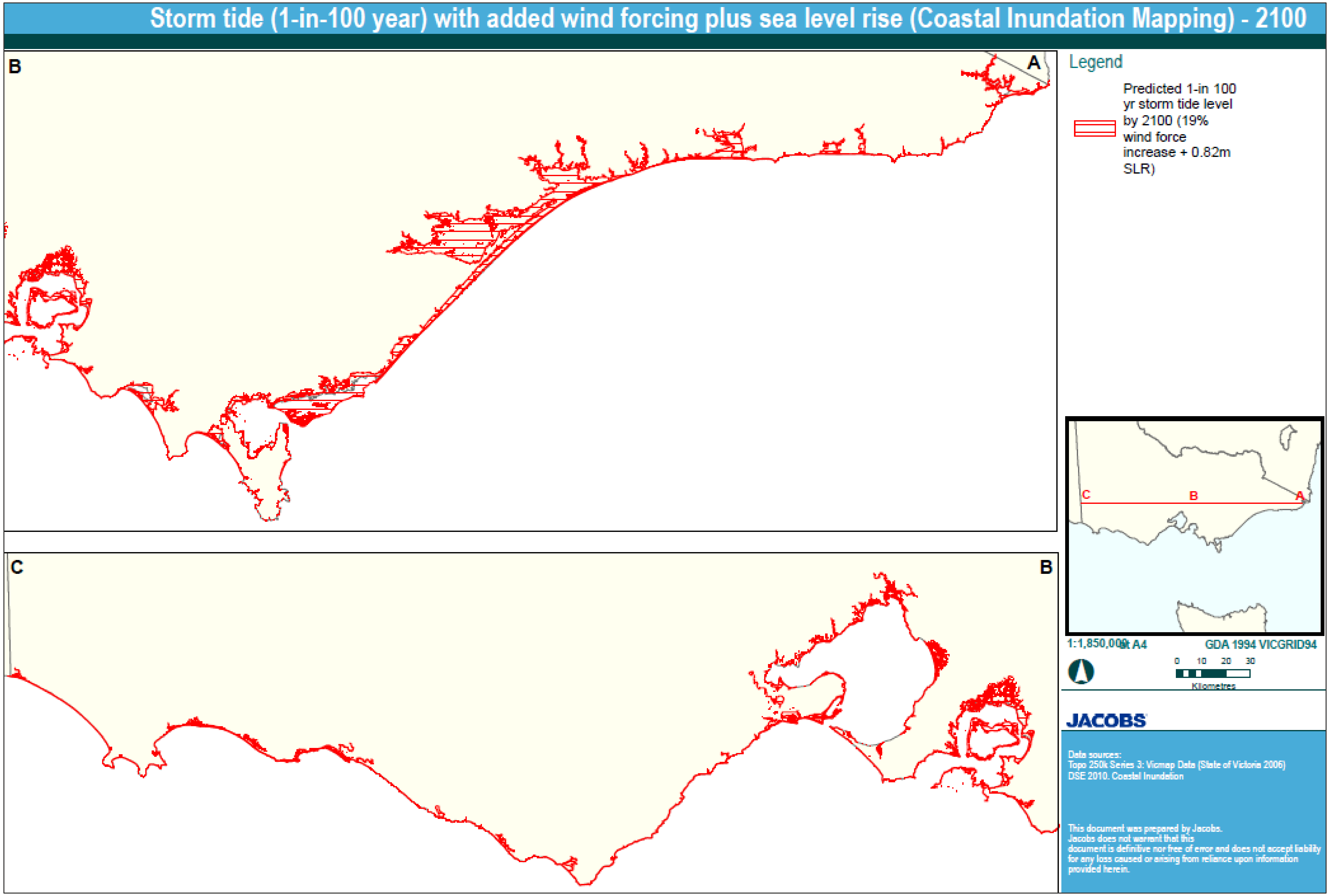


Figure 47: Climate change exposure – Storm tide: 2100 (DSE 2010, Victorian Coastal Inundation spatial dataset is available to download at https://www.data.vic.gov.au/)

delwp.vic.gov.au