Environment Protection and Biodiversity Conservation Act 1999 **(EPBC Act) (s266B)**

Approved Conservation Advice (including Listing Advice) for the *Assemblages of species associated with open-coast salt-wedge estuaries of western and central Victoria* ecological community

1. The Threatened Species Scientific Committee (the Committee) was established under the EPBC Act and has obligations to present advice to the Minister for the Environment (the Minister) in relation to the listing and conservation of threatened ecological communities, including under sections 189, 194N, 266B 269AA of the EPBC Act.
2. The Committee provided its advice on **Assemblages of species associated with open-coast salt-wedge estuaries of western and central Victoria** ecological community to the Minister as a draft of this Conservation Advice in 2018. The Committee recommended that:
   - the ecological community merits listing as Endangered under the EPBC Act; and
   - a recovery plan is not required for the ecological community at this time.
3. In 2018, the Minister accepted the Committee's advice, adopting this document as the approved Conservation Advice. The Minister amended the list of threatened ecological communities under section 184 of the EPBC Act to include ***Assemblages of species associated with open-coast salt-wedge estuaries of western and central Victoria*** ecological community in the **Endangered** category.
4. A draft Conservation Advice for this ecological community was made available for expert and public comment for a minimum of 30 business days. The Committee and Minister had regard to all public and expert comment that was relevant to the consideration of the ecological community.
5. This *approved* Conservation Advice has been developed based on the best available information at the time it was approved; this includes scientific literature, advice from consultations, and existing plans, records or management prescriptions for this ecological community.

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1. CONSERVATION OBJECTIVE

To mitigate the risk of extinction of the ***Assemblages of species associated with open-coast salt-wedge estuaries of western and central Victoria*** ecological community, and assist recovery and maintain its biodiversity and function, through the protections provided under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), by guiding implementation of management and recovery through the recommended priority conservation and research actions.

2. DESCRIPTION OF THE ECOLOGICAL COMMUNITY

The ecological community is the assemblage of native plants, animals and micro-organisms associated with the dynamic salt-wedge estuary systems that occur within the temperate climate, microtidal regime (< 2 m), high wave energy coastline of western and central Victoria. The ecological community currently encompasses 25 estuaries in the region defined by the border between South Australia and Victoria and the most southerly point of Wilsons Promontory.

Geomorphically, the estuaries of the ecological community are drowned river-valley and barrier built systems. They are generally narrow and shallow, although some may have wider lagoons or deeper pools along their length. The mouths[1] of the estuaries are west- and east-facing and typically form a sandbar (or berm) which may overlay a sill[2]. These estuaries are influenced by seasonal longshore sand drift and characterised by intermittent mouths (sometimes open and sometimes closed).

Salt-wedge estuaries are usually highly stratified, with saline bottom waters forming a 'salt-wedge' below the inflowing freshwater layer of riverine waters. The wedge of heavier marine waters is introduced into the estuary by wave energy and tides. There is typically a well-formed halocline boundary between the two water-column layers, which may vary in size from a few centimetres to 1–1.5 m (Sherwood 1983; Newton 1994; Mondon et al. 2003). Mixing at this boundary causes the surface layer to entrain saltwater and become more saline as it moves seawards. To compensate for the entrained saltwater, there is a slow movement of the deeper saltwater layer upstream. Over a standard annual hydrological cycle, the salt-wedge may be in one of three main phases: emplacement (i.e. formation); presence, or; reduction (i.e. retreat) which may extend to complete flushing (Newton 1994, 1996). A detailed description of the hydrological cycle of salt-wedge estuaries is at Appendix C.

The dynamic nature of salt-wedge estuaries has important implications for their inherent physical and chemical parameters, and ultimately for their biological structure and ecological functioning. Some assemblages of biota are dependent on the dynamics of these salt-wedge estuaries for their existence, refuge, increased productivity and reproductive success. The ecological community is characterised by a core component of obligate estuarine taxa, with associated components of coastal, estuarine, brackish and freshwater taxa that may reside in the estuary for periods of time and/or utilise the estuary for specific purposes (e.g. reproduction, feeding, refuge, migration). The composition and abundance of taxa may vary between the different salt-wedge estuaries, as well as at different phases of salt-wedge emplacement, presence or reduction. Further information on biology and ecology of the ecological community is at Appendix C.

[1] The mouth of an estuary is its seaward opening to the ocean.
[2] A sill is a shelf of rock at the entrance of a river mouth (estuary). The sill restricts circulation of deeper waters with the adjacent ocean.

2.1. Name of the ecological community

The ecological community is named ***Assemblages of species associated with open-coast salt-wedge estuaries of western and central Victoria*** (hereafter referred to as the 'Salt-wedge Estuaries ecological community' or the 'ecological community').

The description of the ecological community has been refined from an original public nomination to list a broader ecological community, '*The community of estuarine species dependent on salt-wedge estuaries of southern Australia*' that was placed on the 2012 Finalised Priority Assessment List. The original nomination contained 157 potential salt-wedge estuaries in Victoria, Tasmania, South Australia, southern New South Wales and southern Western Australia. These estuaries can be classified into 'natural' subsets across the geographical expanse of southern Australia based on differences in climate, oceanography and biogeography (i.e. speciation patterns, paleo-barriers) (McSweeney et al. 2017). Following consultation with experts during the assessment and taking into account ecological and biogeographical differences, the definition of the ecological community was narrowed to focus on a naturally occurring subset of estuaries; the open-coast salt-wedge estuaries of central and western Victoria.

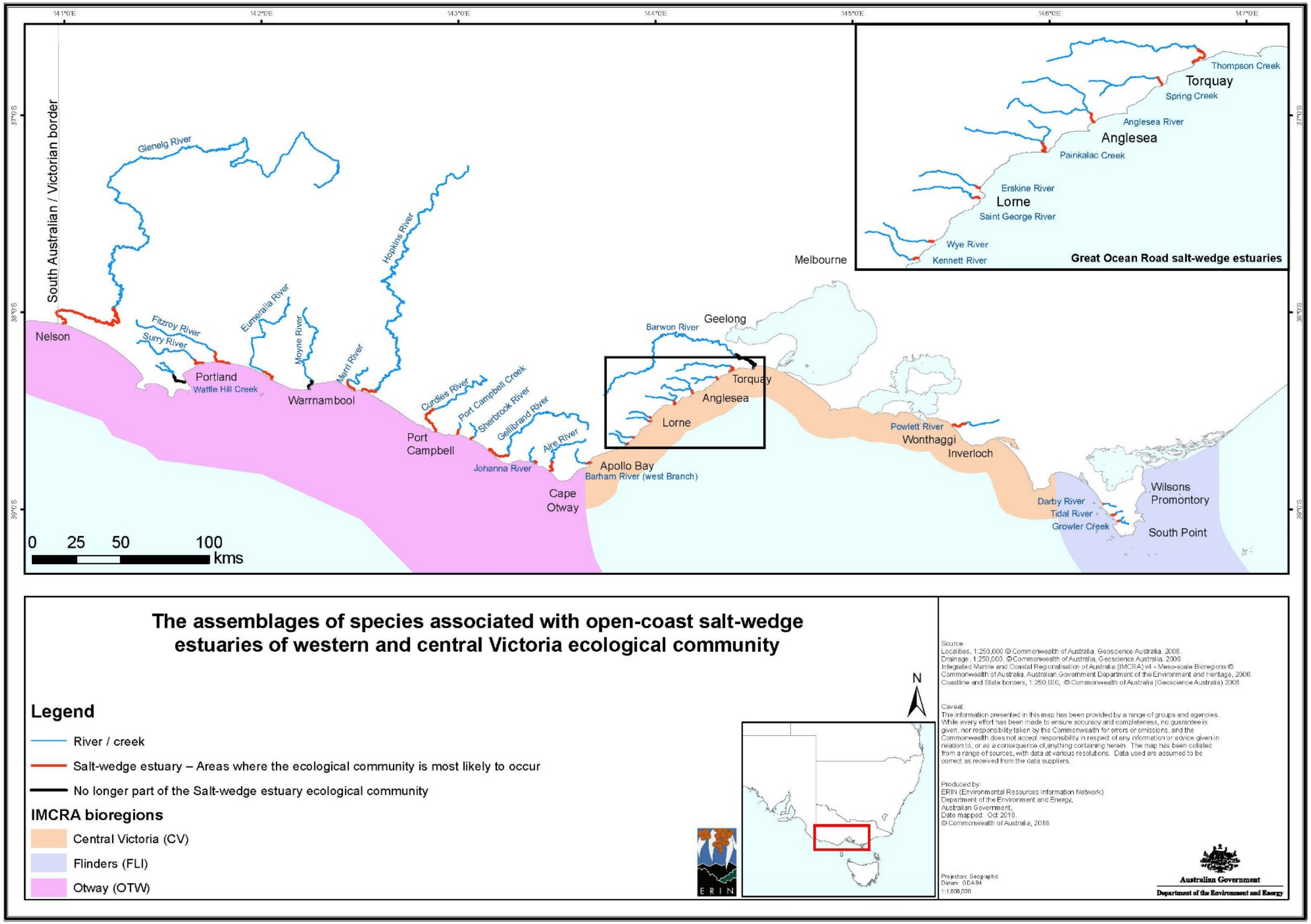
2.2. Location and physical environment

The ecological community occurs along the western and central coastlines of Victoria between the border of South Australia and Victoria and South Point of Wilsons Promontory (Figure 1).

Biogeography is recognised as an important framework for describing patterns of biodiversity (Edmunds et al. 2000; Waters et al. 2010). The ecological community spans a unique geographical and climatic region defined by the overlap of the Flindersian and Maugean marine biogeographical provinces (after Bennett & Pope 1953 in Edmunds et al. 2000). This region has a distinctive east to west pattern of turnover for many marine taxonomic groups, with lineages of marine invertebrates common to central and western Victoria typically not detected east of Wilsons Promontory, which marks the Bassian Isthmus, a historical biogeographic marine barrier that was breached in the Holocene (Edmunds et al. 2000; O'Hara & Poore 2000; Waters & Roy 2003; Hirst 2004, Waters et al. 2010; Colgan 2016). Walters et al. (2005) suggest that the flow characteristics of the East Australian Current and Leeuwin Current have helped to maintain this biogeographical disjunction (see also Chiswell et al. 2003). Thus, the Great Australian Bight to the west and Wilsons Promontory to the east delimit a biogeographic group of estuaries included in this ecological community. The chosen grouping of the 25 salt-wedge estuaries largely concurs with classification studies of Victoria's estuaries (Barton 2003, 2006; Barton et al. 2008). The nature of the coast (open or sheltered) and the direction of the coastline, are considered the most practical for grouping Victoria's estuaries for biological factors and management purposes (Barton et al. 2008). It should be noted that estuaries less than one kilometre in length and less than 1.5 metres in depth were excluded from the ecological community; furthermore, estuaries that are currently heavily modified or marinised[3] were also excluded.

[3] In the context of this document, the term 'marinised' refers to the conversion of an estuary to functionally a marine system; i.e. with mixed salinity of close to marine levels, and a distinct lack of salinity stratification.

Figure 1: Distribution



In relation to Barton's et al. (2008) groupings, the ecological community occurs within salt-wedge estuaries on the open-coast from the South Australia border to Cape Otway group (with west facing mouths), the Cape Otway to just west of Port Phillip Bay group (with east facing mouths), and east of Westernport Bay to Wilsons Promontory group (with west facing mouths), which are of a wider more lagoonal shape and more often are dominated by a coastal marine fauna with fewer estuarine species.

Growing evidence supports that Wilsons Promontory has considerable biogeographical significance for Australia's southern temperate marine region (Waters et al. 2005). Wilsons Promontory represents the northern extension of a granite ridge in the Bass Strait region that was not breached until sea levels exceeded -50 m, around 10 000 years ago (Davies 1974). It is considered a biogeographical disjunction, or palaeogeographical barrier (i.e. the Bassian Isthmus), for Australia's temperate marine fauna (Waters et al. 2004, 2005, 2010; Colgan 2016).

The ecological community lies adjacent to the Bioregions of Otway, Central Victoria and a small section of Flinders (IMCRA v4.0[4]) (Commonwealth of Australia, 2006). There are no salt-wedge estuaries in the South Australian component of the Otway bioregion, although a small component of the Glenelg River passes briefly into South Australia. The distance from the Glenelg River (the most westerly estuary) to Growler Creek (the most easterly estuary) along the coastline is 743 km (including the straits of Port Phillip Bay and Western Port Bay, which combined are 32.5 km). The latitude and longitude, lengths of salt-wedge penetration, average width and estimated surface area of each estuary that the ecological community occurs within are provided in Table 1.

> In contrast to the salt-wedge estuaries of the ecological community; Intermittently Closed/Open lakes and Lagoons (ICOLLs) are more typical of eastern Victoria and the New South Wales coast. These estuaries operate very differently in terms of their annual and tidal cycles, and are under a different climatic regime with a less distinct winter rainfall maxima. ICOLLs are often partially to fully mixed, with less stratification, and while there are exceptions (e.g. parts of the Gippsland Lakes), their ecology is usually quite different from that of salt-wedge estuaries.

[4] IMCRA v.4.0: Integrated Marine and Coastal Bioregionalisation of Australia Version 4.0 is the product of the combination of the Interim Marine and Coastal Regionalisation of Australia (IMCRA v3.3), which provided a marine regionalisation of inshore waters, with the National Marine Bioregionalisation (NMB) for off-shelf waters. In combining the two national scale marine regionalisations, IMCRA v4.0 covers Australia's waters from the coast to the edge of the Exclusive Economic Zone excluding Antarctica and Heard and Macdonald Islands. The definition of IMCRA v3.3 bioregions is based on broadscale patterns, evident within a combination of biological and physical data. During the initial evaluation process, the primary biological data sets that were available across a large enough spatial scale were for sponges, corals, fishes and seagrasses (IMCRA, 1998).

Table 1: The location coordinates and physical description of each estuary within which the ecological community occurs, from the South Australia/Victoria border to Wilsons Promontory. *[Note: The estuaries included are ≥ 1 km in length and ≥ 1.5 m in depth, but estuaries of those dimensions are excluded if they were heavily modified/marinised prior to listing]*.

Estuary	Length (km) *	Mouth	Longitude	Latitude	Av. Width# (m)	Estimated Surface Area (ha)
Glenelg River	67.9	Intermittent	140.988595	-38.059238	81	552.0
Surry River	7.0	Intermittent	141.703086	-38.259308	26	18.0
Fitzroy River	12.9	Intermittent	141.855085	-38.262486	28	36.5
Eumeralla River (Lake Yambuk)	8.1	Intermittent	142.044417	-38.337988	124	100.0
Merri River (East)	7.4	Intermittent	142.471169	-38.40158	361	54.1
Hopkins River	9.6	Intermittent	142.508439	-38.40219	170	163.3
Curdies River	18.6	Intermittent	142.880747	-38.608183	186	346.6
Port Campbell Creek	2.8	Intermittent	142.990555	-38.620555	81	1.6
Sherbrook River	1.9	Intermittent	143.032400	-38.385500	26	3.0
Gellibrand River	13.8	Intermittent	143.156592	-38.706124	28	33.7
Johanna River	2.4	Intermittent	143.387777	-38.769999	124	1.9
Aire River	8.0	Intermittent	143.460526	-38.806664	361	103.0
Barham River	2.8	Intermittent	143.675635	-38.762782	170	13.6
Kennett River	1.2	Intermittent	143.853611	-38.668055	13	1.5
Wye River	1.0	Intermittent	143.890000	-38.636666	5	0.5
St George River	1.5	Intermittent	143.975277	-38.536666	17	2.5
Erskine River	1.0	Intermittent	143.978333	-38.533888	33	3.3
Painkalac Creek	3.6	Intermittent	144.100911	-38.468704	35	12.5
Anglesea River	2.6	Intermittent	144.191308	-38.414485	65	17.0
Spring Creek	2.1	Intermittent	144.318653	-38.343317	20	4.1
Thompson Creek	5.5	Intermittent	144.377109	-38.303062	47	25.8
Powlett River	8.6	Intermittent	145.511527	-38.584201	35	30.0
Darby River	1.1	Intermittent	146.269	-38.973	21	2.4
Tidal River	2.4	Intermittent	146.314445	-39.032913	34	8.2
Growler Creek	1.3	Intermittent	146.341	-39.061	55	7.1
TOTAL						**1542.2**

* Estimate of maximum length of salt-wedge penetration (after Mondon et al. 2003, Barton et al. 2008 and Pope et al. 2015). Note: for estimated surface area of estuary, polygons were derived from Vicmap Hydro watercourses and water area parcels with additional seaward boundaries derived from the vcst25g_coastline database. Estuary Head position and mouth type reviewed and surveyed as described in metadata of Pope et al. (2015).

Average width determined by back calculation of estimated surface area using mapping techniques and known length of salt-wedge estuary (A. Pope pers. comm. 2016).

2.3. Climate and hydrodynamics

The region of the ecological community corresponds with a temperate, maritime climate which is characterised by peak late-winter to early-spring rainfall, and warm, dry summers. This ‘winter-wet, summer-dry’ pattern results in seasonal changes in river/estuary discharge. Peak discharges in late-winter to early-spring (August–September) are typically up to twenty times higher than the autumn minima in March–April (Mondon et al. 2003). The Victorian coast west of Wilsons Promontory receives rainfall of around 500–700 mm per year, usually with a winter maximum (Grose et al. 2015). The variation in freshwater input results in significant seasonal changes to salinity within estuaries (Sherwood 1985) and also influences the length of salt-wedge penetration (Mondon et al. 2003).

A salt-wedge estuary is formed when the intrusion of sea water along the bed of the estuary becomes thinner with distance upstream. The physical separation of marine and riverine derived water within the estuary, with the denser salty marine water sitting beneath the riverine water forms the wedge. The main factors that drive salt-wedge dynamics and the diversity, distribution and habitat of biota in the ecological community are hydrology, salinity, regional climate, tidal regime, transport of sediment, nutrients and carbon, and connectivity (Newton 1994; Rogers & Ralph 2011; Pope et al. 2015; McSweeney et al. 2017). These factors, as outlined in Figure C2, combine to influence processes such as salinity stratification, water mixing, erosion, and transport and deposition of sediments and organisms. Further information on hydrology of the ecological community is at Appendix C.

2.4. Flora and protista

Primary producers of the ecological community include macrophytes[5], phytoplankton[6], and protists[7] (refer Table 2 and Appendix A1). These occur in the water-column, on associated substrates, on submerged or intermittently submerged riparian vegetation along the estuary margins (e.g. *Phragmites australis*, *Ruppia spp.*, *Potamogeton crispus*, *Triglochin procera*) and in seagrass beds in lower to mid reaches (e.g. *Zostera muelleri*) (Newton 1994; Walsh 1994; Ierodiaconou & Laurenson 2002). The composition of flora and protista species may vary across the different estuaries within the ecological community. Fringing wetlands and riparian vegetation adjacent to the main channel may occur and, although not part of the ecological community, are included in associated buffer zones.

The estuarine phytoplankton is dominated by diatoms (Rouse 1998). In the Hopkins River estuary, Rouse (1998) recorded 55 species of diatom and seven species of dinoflagellate. Common and often abundant diatoms of the ecological community are species of genera *Pleurosigma* and *Synedra*, which occur in the water-column and in benthic and epiphytic habitats (i.e. microphytobenthos). Other common members of the microphytobenthos are the diatoms *Navicula* and *Nitzschia* species. The colony forming diatoms *Melosira* and *Nitzschia (Bacillaria) paradoxa* may also be common in the water-column. Dinoflagellates[8] are known to be present in

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[5] A macrophyte is an aquatic plant that grows in or near water and is either emergent, submergent, or floating.

[6] Phytoplankton is plankton consisting of microscopic flora (freshwater, marine and estuarine).

[7] Protists belong to the kingdom Protista. These are the eukaryotic organisms (organisms with a nucleus) that are not animals, plants or fungi. They may occur as unicellular, multicellular, coenocytic, or colonial organisms. They include: protozoa, the animal-like protists; algae, the plant-like protists; and slime moulds and water moulds, the fungus-like protists.

[8] Dinoflagellates are single-celled organism with two flagella, may occur in marine or freshwater environments.

the Hopkins River and most likely occur in the other estuaries, with *Prorocentrum minimum*, *Dinophysis caudata* and *Ebria tripartita* often abundant in low flow periods (Newton 1994; Rouse 1998). Nanophytoplankton[9] is likely to form a dominant fraction at times (Newton 1994; Perissinotto et al. 2010). During high flow periods, freshwater blue-green algae (e.g. *Oscillatoria*, *Ankistrodesmus*), green algae (e.g. *Oocystis* and *Eudorina*) and desmids[10] (e.g. *Closterium* and *Staurastrum*) are likely to be present in the water-column. Other protists such as anaerobic ciliates and photosynthetic sulphur bacteria may also be important in the deeper anaerobic/anoxic waters (Rouse 1998).

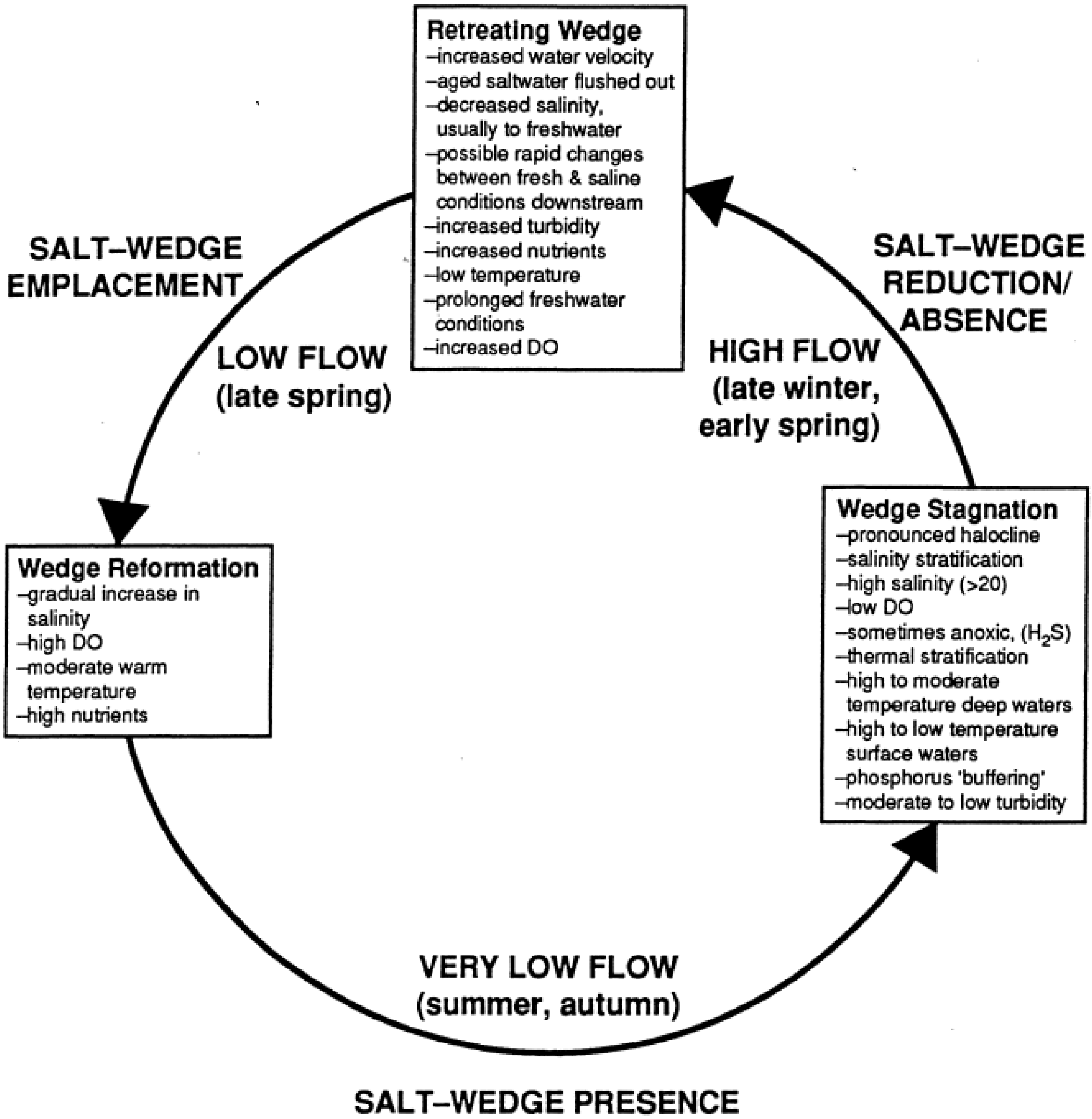

Figure 2: *Generalised hydrodynamic cycle of central and western Victorian salt-wedge estuaries (Sherwood 1985; Newton 1994).*

[9] Nanophytoplankton are planktonic organisms 2–20 µm in diameter.
[10] Desmids are single-celled freshwater green alga of the family Desmidiaceae, characterized by a division of the body into mirror-image halves joined by a bridge containing the nucleus, and having a spiny or bristly exterior.

2.5. Fauna

Zooplankton[11], principally copepods, such as *Gippslandia estuarina* and *Gladioferens pectinatus*, constitute the major secondary producers and drivers of productivity in the ecological community (Newton 1994). Copepods live permanently in the water column (i.e. holoplankton[12]), while a proportion of the zooplankton assemblage also consists of the larvae of nektonic[13] and benthic[14] fauna (i.e. meroplankton[15]). Meiofauna[16] (e.g. harpacticoid copepods, amphipods), the small invertebrates that inhabit aquatic sediments and submerged vegetation, are also important in the transfer of energy through the ecosystem. Larger benthic and nektonic fauna include polychaete worms, molluscs, crabs, shrimp and fish. Estuarine fish species such as *Acanthopagrus butcheri* (black bream) and *Macquaria colonorum* (estuary perch) are apex predators. Functional groups and dominant taxa of the ecological community are provided in Table 2, Appendix A2 (zooplankton) and Appendix A3 (fish).

Table 2: Functional groups and/or dominant taxa that utilise the ecological community (Newton 1994, 1996; Walsh & Mitchell 1995; Arundel 2003; R Shiel pers. comm. 2016; see Appendix A).

TAXA - Type	TAXA - Examples
Core Estuarine Obligates Typically species which live and propagate only in the estuary; true estuarine endemic species; often keystone species.	• Diatoms (certain species of) - benthic (e.g. *Pleurosigma, Synedra*), colonial (e.g. *Melosira* and *Nitzschia*) and pelagic (e.g. *Chaetoceros*) • Holoplankton grazers (secondary producers) – Calanoid copepods (e.g. *Gippslandia estuarina* and *Gladioferens pectinatus*) • Holoplankton predators – Calanoid copepods (e.g. *Sulcanus conflictus);* Cnidarian (*Australomedusa baylii*) • Meroplankton (larvae of benthic and nektonic fauna) – crab zoea (e.g. *Amarinus laevis* and *A. paralacustris*); spionid polychaete larvae (e.g. *Carazziella victoriensis, Prionospio tatura, Orthoprionospio cirriformia*); caridean shrimp larvae (e.g. *Paratya australiensis*); bivalve larvae; fish larvae • Meiobenthic/Phytal – Harpacticoid copepods (e.g. Ectinosomatid spp., *Mesochra* spp., *Amphiascoides* spp. nov., *Onychocamptus chathamensis*, *Australonannopus aestuarinus*) • Macro-invertebrate benthos –spionid polychaete (e.g. *Carazziella victoriensis, Prionospio tatura, Orthoprionospio cirriformia*), shrimp (e.g. *Paratya australiensis* estuarine form) • Nekton - Fish – *Acanthopagrus butcheri* (black bream), gobies (e.g. *Pseudogobius* sp. (bluespot goby))
Common Estuary Dwellers/Residents Common/abundant species that may live and reproduce in the estuary but are not necessarily estuarine-endemic.	• Dinoflagellates (mostly marine neritic forms (e.g. *Dinophysis caudata* and *Prorocentrum minimum*) • Seagrasses (e.g. *Zostera muelleri*, *Ruppia* spp. and *Heterozostera tasmanica*) and riparian vegetation (e.g. *Phragmites australis*) • Rotifers – brackish species (e.g. *Brachionus plicatilis*, *Lecane* spp., *Keratella* spp.) • Meiofauna/Benthic Macroinvertebrates – harpacticoid copepods, cyclopoid copepods, ostracods, nematodes, polychaetes (e.g. *Australonereis ehlersi*

[11] Zooplankton constitute the animal component of the plankton, typically of small size up to 2 mm. They are divided into permanent members of the plankton and temporary members (i.e. larval forms). Many zooplankton species graze on phytoplankton (plants).
[12] Holoplankton are the permanent members of the zooplankton that live their entire life-cycle in the pelagic zone (e.g. copepods).
[13] Nektonic fauna comprises aquatic animals that are able to swim and move independently of water currents.
[14] Benthic organisms live on or in the bottom substrate of a waterway.
[15] Meroplankton are temporary members of the zooplankton that are the early-life history forms of animals that live either in the water-column as adults (e.g. fish) or among the benthos as adults (e.g. polychaete worms).
[16] Meiofauna are minute benthic invertabrates usually 45 - 100µm in diameter.

TAXA - Type	TAXA - Examples
	(nereid)), molluscs (e.g. *Soletellina alba*), crabs (e.g. *Amarinus* spp.); caridean shrimp (e.g. *Palaemon intermedius*, *Palaemon serenus*) • Nekton - Fish – *Macquaria colonorum (*estuary perch), gobies (e.g. *Arenigobius bifrenatus* (bridled goby)), and gudgeons (e.g. *Philypnodon grandiceps* (flat-head gudgeon)) • Birds – various waterbirds and waders (some migratory), and riparian passerines, raptors, parrots
Seasonal Dependents/ Opportunists Species that utilise the estuary (and associated riparian and wetland zones) periodically for migrations, and/or opportunistically for reproduction, or feeding).	• Freshwater phytoplankton (during high flows) diatoms, algae (e.g. *Oocystis and Eudorina*), blue-green algae (e.g. *Oscillatoria, Ankistrodesmus*) • Rotifers – freshwater species (e.g. *Brachionus* spp., *Keratella* spp. • Cladocerans – e.g. *Daphnia* spp., *Bosmina meridionalis*, *Alona* spp. • Marine/Freshwater fish – for nursery function/reproduction (e.g. marine *Engraulis australis* (anchovy)); *Galaxias maculatus* (common galaxias)); *Prototroctes maraena* (Australian grayling)); *Anguilla australis (*short-finned eel); *Pseudaphritis urvilli (tupong)* • Euryhaline-marine group – e.g. larvacean, *Oikopleura dioica*; *Catostylus mosaicus* (jelly blubber) • Birds – various waterbirds and waders (some migratory), and riparian passerines, raptors, parrots; utilising the area opportunistically and seasonally for feeding and for breeding.
Incidental Strays Species that <u>do not</u> characterise the ecological community but may occur in the estuary at times	• Freshwater strays (i.e. during flood events) – Calanoid copepods (e.g. *Sulcania* spp..); rotifers (e.g. *Brachionus* spp., *Keratella* spp., *Filinia longiseta*); cladocerans (e.g. *Alona* spp., *Bosmina meridionalis*, *Chydorus* spp., *Daphnia* spp.); *Euastacus bispinosus (Glenelg spiny freshwater crayfish)* • Marine strays (i.e. from adjacent marine waters during peak tides, astronomical surges) – copepods (e.g. *Acartia*, *Oithona*); polychaetes (e.g. *Carazziella* spp., *Polydora* spp.); fish larvae (e.g. Clinidae, Tetraodontidae, Tripterygiidae); seabirds (e.g. gannet, shearwater)

2.6. Key diagnostic characteristics

National listing focuses legal protection on remaining patches of the ecological community that are most functional, relatively natural and in relatively good condition. Key diagnostic characteristics are a summary of the main features from the description for the ecological community. They assist with determining whether the ecological community is present at a particular time, and place, and when the EPBC Act is likely to apply to the ecological community. The key diagnostic characteristics of the ecological community are outlined in Table 3.

Importantly estuaries that were shorter than 1 kilometre were excluded from the ecological community as they are generally quite steep therefore the formation of a salt-wedge and inhabitation by associated biota is limited and intermittent (e.g. those at the foot of the Otways, backed by cliffs and waterfalls). These shorter estuaries are generally also subject to greater marine influence due to their short length (particularly in low flow conditions), and can accumulate large amounts of seaweed leading to poor water quality.

Table 3: Key Diagnostic Characteristics of the Salt-wedge Estuaries ecological community**.**

Aspect	Key Diagnostic	Comment
IMCRA Marine Bioregion	Mesoscale bioregions of Otway, Central or Flinders, Victoria	There are no South Australian salt-wedge estuaries in the ecological community (although a short section of the Glenelg River flows through South Australia).
Province	Overlap region of Flindersian and Maugean biogeographic provinces	Occurs from South Australia border to South Point, Wilsons Promontory.
Coast	• Adjacent to the southern Australian coastline • Open	• Within the state of Victoria. • Open-coast as opposed to a large Embayment or Inlet (e.g. Port Phillip Bay estuaries are not included).
Climate	Temperate and typically 'Mediterranean' – with peak rainfall in late-winter to early-spring and with warm, dry summers	Overlaps with Koppen climate types *Csb* (Warm-summer Mediterranean) and *Cfb* (Oceanic, with milder, cloudy winters).
Geomorphic Estuary Type	Mainly drowned river valley, barrier built	Typically linear but sometimes with lagoons. May have entrance berm/sill.
Estuary Length	≥ 1 kilometre	Need a minimum length to ensure adequate dimensions for functional wedge to form.
Width	Linear, relatively narrow (apart from lagoons), often with bends	18 estuaries with average width of < 100 m, 7 estuaries with average width within 100-400 m
Depth	Mainly relatively shallow, but may have some deep pools or basins along length	
Wave Energy	High wave energy; Wave dominated system	As opposed to tide dominated.
Tidal Energy	Low tidal energy; microtidal (< 2 m) system	Does not include meso-tidal or augmented tidal conditions.
Hydrology	River dominated; Net-flow seaward	River dominance may wane during extended drought and periods of extreme low freshwater flow.
Salinity	A high degree of vertical salinity stratification for much of the time. Dynamic salt-wedge present at least a proportion of the time leading to the three essential phases of: • Salt-wedge formation/emplacement • Salt-wedge presence/stagnation • Salt-wedge retreat/flushing/removal	Estuaries that are naturally fully mixed for most of the time are not the ecological community. All three phases of salt-wedge dynamics need to occur at times to ensure the sustainable health of the ecological community. The time period of each stage will be largely driven by rainfall and river discharge and is variable and unpredictable. A salt-wedge will form in these estuaries when flow conditions abate and allow seawater to penetrate them. Given the region's temperate climate, such conditions are met in the majority of years. However, longer-term exceptions may occur during extended drought conditions.
Mouth Opening	• Intermittent (naturally) • West or East facing (not South)	Naturally occurring mouth opening and closure is a function of climate, rainfall and discharge. Note: a permanently open or permanently closed mouth is not ideal to ecology/productivity.
Mouth Morphology	Typically presence of a sandbar (berm) and sometimes a sill (rockbar) or both	A sandbar or berm is formed at the mouth by the high wave energy coast and longshore sand drift. There may be an underlying sill. The sandbar (and sill) influences and often limits tidal exchange of organisms and materials, particularly in the deeper layer.
Biota (fauna & flora)	Likely to contain species presented in Table 2 and Appendix A (including taxa that may only occur in the ecological community).	There will be variations in species composition across different estuaries.

2.6.1. Reference condition

For some nationally-listed ecological communities, condition classes and thresholds are specified to focus legal protection on patches that remain in relatively good condition, and largely retain their natural composition and ecological function. Due to the dynamic nature of the Salt-wedge Estuaries ecological community and the importance of longitudinal and lateral connectivity, the Committee determined that, in this case, condition thresholds do not apply.

However, the Hopkins River estuary, the most extensively studied of the estuaries in the ecological community, provides a functioning 'reference condition' for the ecological community. Establishing an appropriate reference condition is important to enable robust detection of any significant deviations in condition and appropriate management responses (Hallett et al. 2016b). Scarcity of historical data precludes the use of pre-European (or pre-regulation) conditions as a reference condition. Nonetheless, the Hopkins River estuary was studied extensively in the mid to late 1980s and early 1990s (i.e. prior to the Millennium Drought) (Barton et al. 2008) and found to be in a 'typical' and highly productive condition during that period (Newton 1994, 1996; Walsh 1994; Walsh & Mitchell 1995). The state of the Hopkins River estuary as characterised during the mid-1980s and early 1990s is therefore assumed to be indicative of a functioning reference condition for the ecological community across its geographic distribution.

2.6.2. Boundaries and buffer zones

Buffer zones can enhance protection of a component of an ecological community by avoiding or minimising potential physical disturbance from surrounding land and sea uses. While the buffer zone is not formally part of the ecological community, it should be taken into account when considering likely significant impacts during EPBC Act decision-making.

The estuaries of the ecological community each have well defined boundaries, both longitudinally (i.e. mouth to upstream limit of salt-wedge penetration) and laterally (i.e. the river channel, banks and submerged or intermittently submerged riparian and wetland vegetation).

Providing riparian buffers of sufficient width, especially in the headwaters, protects and improves water quality by intercepting and trapping non-point source pollutants and sediments in surface and shallow subsurface water flow (Wenger 1999; Fischer et al. 2000). Some higher level benefits of buffer zones include: maintaining ecological integrity, minimising edge effects, building resilience against climate change and protecting groundwater (Newton 2012). There are four types of buffer zone proposed for the ecological community - upstream, downstream, laterally and groundwater.

Further details on the boundaries and buffer zones of the ecological community are provided in Table 4.

Table 4: Boundaries and buffer zones for the Salt-wedge Estuaries ecological community.

Aspect	Boundary	Comment
Landward boundary per salt-wedge estuary in the ecological community	Defined by the maximum (natural) upstream limit of salt-wedge penetration.	This is usually just before or equivalent to the length of tidal penetration/influence. Some estuaries may have natural landward boundary limits e.g. old lava flow at Tooram Stones for the Hopkins River and the rock bar at Deen Maar bridge for the Eumeralla River (DELWP 2017b).

Aspect	Boundary	Comment
Seaward boundary per salt-wedge estuary in the ecological community	Defined by the line drawn between the seaward edge on each side of the estuary mouth.	During high flow periods there may be a 'plume' of estuarine/fresh water that extends from the estuary into the adjacent ocean. The plume outside the mouth no longer forms part of the ecological community but does form part of the marine buffer zone (see below).
Vertical	• The water-column from the surface of the estuary/river to the boundary layer with the bottom substrate, and • The bottom substrate of the estuary from the mouth to the landward boundary.	
Lateral	The entire channel (or lagoon) width to the littoral margins on each side, including the extent of typically submerged littoral vegetation and seagrass beds.	If downstream seagrass beds are exposed at low tide they still remain part of the ecological community. Wetlands connected to the main stem of the estuary are not part of the ecological community but may fall within a buffer zone (see below).
Buffer Zones	• Upstream of the salt-wedge limit is considered a 'zone of influence' for the ecological community. Therefore the entire parent river catchment system and tributaries upstream, together with their riparian vegetation, should be considered as a buffer zone. • The adjacent marine region to a radius of 1000 m outside of the estuary mouth, including ocean, beach and dune areas. • A lateral buffer zone of a minimum of 50 m from the lateral edge of the estuary into the typically exposed adjacent riparian zone and associated wetlands (Boyd 2001), intertidal, mud and sand flats, beach and foreshore environments up to the limit that these are affected by extremes in tidal or fluvial flood events.* • A 200 m minimum buffer zone for groundwater[#]. An appropriate buffer may be 2000 m for example.	The buffer zones are not considered part of the ecological community and therefore in their own right do not trigger the EPBC Act. However they should be considered when determining likely 'significant impact' on the ecological community. The lateral buffer zone helps to protect bank stability and water quality, and reduce nutrient and sediment inputs, especially from adjacent urban areas. Similar buffer zone distances have been applied to several other ecological communities listed as threatened under the EPBC Act (Newton 2012). The groundwater buffer zone aims to protect against groundwater drawdown and protect inflowing groundwater quality. The variable size depends on the intensity of the likely impacts of the threat (Newton 2012).

* (After Adam et al. 1992)
# (After Newton 2012).

2.6.3. Area critical to the survival of the ecological community

Areas that meet the key diagnostic characteristics plus an appropriate buffer zone are considered critical to the survival of the ecological community.

Of critical importance to the survival of the ecological community is a hydrological regime sufficient to ensure salinity stratification; salt-wedge dynamics; connectivity; and ecological function between the estuary, river and ocean (and floodplain wetland components where applicable). Changes in catchment management (e.g. land-use changes that change water flow, sediments, water seasonality etc.) have the potential to, and have previously, affected the survival of the ecological community (DELWP 2017b).

The area critical to the survival of the ecological community is also considered to be:

- the parent river, catchments and tributary systems of the estuaries within the ecological community (captured in the buffer zones outlined in Section 2.6.2);
- seasonally submerged and inundated riparian and wetland vegetation associated with each estuary within the ecological community;
- the beach, sand dune and sandbar structures, and native vegetation that form part of, or are adjacent to, each estuary mouth and therefore influence condition of the mouth;
- the sediments (or cliffs/ridges where applicable) and native riparian vegetation of the banks and associated floodplain (where applicable) of each estuary; and
- the coastal, tidal marine waters adjacent to each estuary mouth.

2.6.4. Surrounding environment and landscape/seascape context

In the context of actions that may have 'significant impacts' and require assessment under the EPBC Act, it is important to consider the environment that surrounds the ecological community, including the catchment areas of the parent river systems. The following additional indicators should be considered when assessing the impacts of actions or proposed actions under the EPBC Act, or when considering recovery, management and funding priorities for a particular estuary or area of the ecological community:

- Adequate hydrological flows (river and tide), with supporting natural seasonal characteristics (i.e. winter/spring) for ecological function, management and monitoring of the intermittent nature of the estuary mouth (including ‘appropriate’ artificial opening), and occurrence of the necessary stages of the dynamic salt-wedge hydrological cycle.
- The unimpeded movement of mobile species and the longitudinal extent of the salt wedge (for example weirs and tidal barrages may impede critical movement).
- Maintenance of fringing wetlands, healthy submerged and riparian flora (including terrestrial native vegetation) and intact river/estuary banks.
- Evidence of recruitment of keystone native species or presence of a range of age cohorts, (e.g. black bream, shrimp, seagrass and copepods).
- Species richness, as shown by the variety and proportion of native flora and fauna present, and presence of unique faunal assemblages associated with the ecological community.
- Presence of listed threatened or migratory species.
- Minimal invasive species (weeds and feral animals).

3. SUMMARY OF NATIONAL CONTEXT

3.1. Ecosystem functions

Estuaries and their wetlands are highly productive areas and ecologically important as they provide habitat and resources for biota, including spawning and nursery areas for fish and invertebrate species, and breeding and foraging areas for birds. Apart from their ecological importance, estuaries are multiple-use resources, tourist attractions, support economic activities, and are also valued for recreation (Baron et al. 2003; Costanza et al. 1997; Hallett et al. 2016a & c).

Ecosystem services include flood control, transportation, recreation, purification of human and industrial wastes, and production of fish and other foods or marketable goods (De Groot et al. 2012). Over the long term, resilient, intact ecosystems are more likely to retain the adaptive capacity to sustain production of these services in the face of environmental disruptions such as climate change. Such services are often impossible to replace when aquatic systems become too degraded (Baron et al. 2003).

3.2. Bioregional and NRM distribution

The ecological community spans four Interim Biogeographic Regionalisation for Australia (IBRA) bioregions and six IBRA subregions (DEE 2017) (see Appendix B1). The ecological community is located in the three Natural Resource Management (NRM) regions and Catchment Management Authorities (CMAs) of Corangamite, Glenelg Hopkins and West Gippsland.

3.3. Other existing protections

3.3.1. EPBC Act protection

There are two listed National Heritage places that occur within the same area as the ecological community; the Great Ocean Road and Scenic Environs, and the Budj Bim National Heritage Landscape (refer to Section 3.4 Indigenous and Cultural Context).

The Apollo Commonwealth Marine Reserve is located outside of the coastal waters zone adjacent to parts of the ecological community and some species that occur within the marine reserve, such as *Engraulis australis* (Australian anchovy), opportunistically utilise the estuaries of the ecological community for feeding and reproduction (Hoedt & Dimmlich 1995).

Parts of the recently listed 22 000 hectare Glenelg Estuary and Discovery Bay Ramsar wetlands are located within the boundaries of the ecological community. In addition, the Piccaninnie Ponds Karst Ramsar wetland is located less than 5 km to the west of Glenelg River estuary in South Australia; Corner Inlet Ramsar wetland is located 5 km to the east of Darby River and Tidal River; Western Port Ramsar wetland is located 10 km west of Powlett River; and Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar wetland is located 5 km east of Thompson Creek (DEE 2017).

There are several Nationally Important Wetlands located within the region of the ecological community. These are: Glenelg Estuary, Glenelg River, Lower Merri River Wetlands, Aire River, Lower Aire River Wetlands, Powlett River Mouth, Yambuk Wetlands Reserve (Eumeralla River) and Princetown Wetlands (Gellibrand River) (DEE 2016). These wetlands and estuaries provide important habitat for EPBC Act listed migratory bird species.

Relationships to EPBC Act listed ecological communities

The Salt-wedge Estuaries ecological community differs from most other EPBC Act listed ecological communities by its coastal position in the landscape that is subject to both freshwater discharge and marine tidal influence. There is currently one nationally-listed coastal wetland ecological community, the *Subtropical and Temperate Coastal Saltmarsh*, which may overlap or form a component within the Salt-wedge Estuaries ecological community (TSSC 2013).

Five other nationally-listed ecological communities have some occurrences that may be located in the vicinity of the riparian zone of the estuaries and/or parent river catchment systems of the Salt-wedge Estuaries ecological community (DEE 2017). These terrestrial ecological communities are expected to have limited linkages to the Salt-wedge Estuaries ecological community. However, they may provide habitat for species that utilise the estuaries of the ecological community for foraging. These ecological communities are:

- *Natural Damp Grassland of the Victorian Coastal Plains*
- *Grassy Eucalypt Woodland of the Victorian Volcanic Plain*
- *Natural Temperate Grassland of the Victorian Volcanic Plain*
- *Seasonal Herbaceous Wetlands (Freshwater) of the Temperate Lowland Plains*
- *White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland.*

The *Giant Kelp Marine Forests of South East Australia* is a nationally-listed marine ecological community found in the waters off the coast of Victoria in the Otway, Flinders and Central Victoria bioregions. This community is offshore and does not directly connect with the Salt-wedge Estuaries ecological community.

3.3.2. State government protections

Parts of the ecological community, namely the Aire River and Glenelg River estuaries, are listed as Heritage Rivers under the *Victorian Heritage Rivers Act 1992*. Victoria formally lists ecological communities as threatened under the *Flora and Fauna Guarantee Act 1988*; there are no estuarine ecological communities listed in Victoria. The Victorian state government classifies vegetation using a system of Ecological Vegetation Classes (EVCs). The ecological community is juxtaposed with two EVCs that are limited to the coastal bioregions in Victoria:

- EVC 9 Coastal saltmarsh aggregate, and
- EVC 10 Estuarine wetland.

Victoria allocates a bioregional conservation status for each EVC in each bioregion that is based on levels of extent and decline (DSE 2007). The status of EVCs 9 and 10 is at Appendix B3.

3.3.3. Nationally threatened species likely to occur in the ecological community

The ecological community contains, and provides habitat and resources for, a wide range of threatened species under the EPBC Act and under the Victorian *Flora and Fauna Guarantee Act 1988*. A list of nationally threatened species that are likely to occur within the ecological community is at Appendix B4. Many of these species utilise the ecological community and its buffer zones but are not permanent residents or known to be integral to the functioning of the ecological community.

The ecological community provides critical habitat for several wetland and coastal waterbirds that come under various international agreements; many of which are listed as migratory under the EPBC Act. A list of the EPBC Act listed migratory bird species likely to occur in the ecological community is at Appendix B5.

3.4. Indigenous and cultural context

The western and central Victorian region has been occupied by Aboriginal people for over 30 000 years (CCMA 2014, 2015). The ecological community, and surrounding areas, would have been occupied by Aboriginal people owing to the proximity to the coastline, access to freshwater, and supply of plant and animal resources (CCMA 2012; GHCMA 2004, 2005; Parks Victoria 2015). The estuaries of the ecological community also would have been of particular importance for travel and ceremonial activities (CCMA 2014). There are approximately eight Indigenous nations and their constituent groups in the region of the ecological community, including the Buandig, Gunditjmara, Giraiwurung, Gadubanud, Wathaurong, Boonwurring and Wadawurrung people (AIATSIS 2017).

The Tyrenndarra Indigenous Protected Area (IPA), located in the Fitzroy River catchment, forms part of the Budj Bim National Heritage Landscape and is sacred to the Gunditjmara people (Builth 2004; GHCMA 2006a). The Tyrendarra IPA features the remains of a large, settled Aboriginal community, which systematically farmed eels for food and trade through traditional aquaculture works (weirs, channels and eel traps) (Framlingham 2004; GHCMA 2006a).

Similarly, the Hopkins River has been identified as providing a significant food source, particularly eels, for local tribes (Framlingham 2004; GHCMA 2005). Stone fish traps have been recorded along the Hopkins River adjacent to apparently natural outcrops of basalt and areas where the river narrows (Hotchin 1980; Schell 1995).

Deen Maar IPA is a coastal property located on the south-west coast of Victoria, bounded by the Eumeralla River and Bass Strait, near the community of Yambuk. It holds spiritual significance to local Aboriginal people and has a spiritual and visual connection with Deen Maar Island (Lady Julia Percy Island) (Framlingham 2004). Remains from conflicts between squatters and Aboriginal people occur on the site (Framlingham 2004). The Deen Maar IPA was also the traditional home of Peek Whurrong speakers of the Dhauwurdwurung (Gunditjmara) Nation, and provided abalone, eels, wild ducks, kangaroos, and plants for food, medicine and housing materials (Framlingham 2004).

Along the coastline, the most common Aboriginal sites are shell middens, where discarded shells have accumulated over time (CCMA 2014). These middens also contain animal bones, artefacts and charcoal. The most common inland Aboriginal sites in the Corangamite region are stone artefact scatters, with campfire remains, scar trees, fish traps and stone houses less common (CCMA 2014).

3.5. Existing plans and management prescriptions

A list of existing plans and management prescriptions related to the ecological community is at Appendix B6.

4. SUMMARY OF THREATS

The distribution of the ecological community is in an area of relatively high coastline utilisation (including agricultural activities and town centres) which makes it susceptible to a variety of environmental stressors. The key threats to the ecological community are summarised below and a detailed discussion of the key threats is at Appendix D.

4.1. Climate change

The effects of human-induced climate change, including reduced rainfall, rising temperature, sea level rise, increased storm activity and ocean acidification, are anticipated to significantly threaten the ecological community. Over time, these changing environmental factors are predicted to substantially alter the spatial extent, hydrology, water quality, ecological processes and aquatic biota of salt-wedge estuaries. Given the occurrence of other stressors, the ecological community is likely to be particularly sensitive to the added impacts of climate change. All 25 estuaries in the ecological community are considered to be threatened by climate change.

4.2. Land use and associated decline in water quality

Intensification of land use for urbanisation, industry and agriculture (including clearing of vegetation) has a significant impact on estuarine water quality. Within the ecological community, 92 percent of the estuaries are affected by land clearing and development (Figure D1a). The key impacts to the ecological community from land use are:

- Eutrophication and algal blooms causing altered levels of dissolved oxygen, shading of seagrasses, toxicity and subsequent mortality of aquatic organisms. It is estimated that 88 percent of estuaries within the ecological community are threatened by increasing rates of eutrophication and algal blooms (Figure D1b).
- Direct and indirect pollution of estuaries from land use activities has resulted in degradation of aquatic habitat and reduced water quality (e.g. acidification, chemical contamination, eutrophication and hypoxia). Within the ecological community, approximately 80 percent of estuaries are considered to be threatened by pollution and contaminants (Figure D1c).
- Land use activities have resulted in increased rates of erosion, runoff and sediment entering the waterways of the ecological community. The implications of increased erosion, sedimentations and turbidity of estuaries include degradation of aquatic habitat, smothering of seagrass and benthic biota, changes in bathymetry and altered biological processes (e.g. reduced photosynthesis, growth, development and oxygen uptake). Within the ecological community, approximately 68 percent of estuaries are considered to be threatened by increasing rates of erosion, sedimentation and turbidity, with an additional 24 percent of estuaries potentially threatened (Figure D1d).
- Acid flows (from exposed acid sulphate soils) and blackwater events (from high levels of organic matter) have significant impacts on the biota of affected estuaries. The implications include widespread mortality of aquatic organisms (e.g. fish kills). Although only 16 percent of estuaries within the ecological community are currently threatened by acid flows and blackwater events, 80 percent of estuaries within the ecological community are considered to be potentially threatened by these events in the future (Figure D1e).

4.3. Modification of flow regime

The balance of seasonal hydrological dynamics that characterises salt-wedge estuaries (Figure 2) is threatened by alterations to both freshwater inflow regimes from feeder streams; and alterations to outflow and saltwater diffusion at the estuary mouth, as a result of the following activities:

- ***Estuary entrance modification***. Approximately 60 percent of estuaries are threatened by artificial mechanical opening of estuary entrances (Figure D1f). Artificial opening is undertaken to prevent flooding to surrounding land. However, this activity can cause the top freshwater layer of the salt-wedge estuary to be lost (drained out to sea), leaving behind the poorly oxygenated saline layer. This may result in mortality of biota (e.g. fish kills) and disruption to biological processes, including faunal migration and spawning.
- ***Water extraction***. Within the catchments of the ecological community, water is extracted and diverted away from parent river systems for domestic, agricultural and industrial use. The impacts of water extraction on the ecological community include reduced downstream freshwater flows to estuaries; altered seasonal flow patterns; reduced flushing of estuaries; longer periods of mouth closure; and poor water quality. Approximately 56 percent of the estuaries within the ecological community are directly threatened by water extraction. An additional 24 percent of estuaries within the ecological community are considered to be potentially threatened by water extraction (Figure D1g).
- ***Water Regulatory Infrastructure***. Regulatory infrastructure, such as reservoirs, weirs, drainage channels and levee banks, and other major infrastructure, such as bridges and road crossings, can form physical barriers, significantly alter natural flow regimes and alter natural physical and biological in-stream processes. Most estuaries within the ecological community contain regulatory and/or other infrastructure within the estuary itself or parent river system. It is considered that 44 percent of the estuaries within the ecological community are threatened by altered hydrological processes, and restriction on movement of biota due, to regulatory infrastructure Figure D1h).

4.4. Invasive species

Estuarine communities are often threatened by invasive species, the implications of which include competition for resources, predation on native species, and alteration and degradation of habitat. Approximately 52 percent of the estuaries within the ecological community are considered to be substantially threatened by invasive species (Figure D1i).

4.5. Disease (pathogens and parasites)

Disease causing pathogens and parasites are a significant threat to estuarine communities as they can alter species' physiology, behaviour and reproduction, and cause widespread mortality in affected populations. Four estuaries within the ecological community are currently known to be affected by pathogens and parasites (Table D3). The remaining estuaries of the ecological community are considered to be potentially threatened in the future.

4.6. Extractive and recreational activities

The key extractive and recreational activities that threaten or potentially threaten the ecological community are commercial and recreational fishing, mining and sand extraction; and recreational boating.

5. RECOMMENDATIONS BY THE THREATENED SPECIES SCIENTIFIC COMMITTEE

5.1. Recommendation on eligibility for listing against EPBC Act criteria

The Regulations of the EPBC Act provide six criteria to determine whether an ecological community is eligible for listing. The assessment of the Salt-wedge Estuaries ecological community against the criteria is summarised below. A comprehensive assessment of eligibility for listing against the EPBC Act criteria is provided at Appendix E.

Criterion 1 – *Decline in geographic distribution*

Within the past 50 years, there has been some decline in geographic distribution (area of occupancy) of the ecological community. For example, in the west, the estuaries of Wattle Hill Creek and the Moyne River have been permanently opened and modified to such a degree that they have become marinised systems (i.e. marine dominated) and are considered irreversibly lost to the ecological community. However, at present, the Committee considers the decline in the geographic distribution of the ecological community to be less than 30% over the past 50 years. Therefore the ecological community is **not eligible** for listing under this criterion.

Criterion 2 –*Limited geographic distribution coupled with demonstrable threat*

The ecological community has a naturally restricted geographic distribution (area of occupancy < 100 km^2). It consists of a series of relatively linear, narrow and short estuarine sections of the parent river systems. The specific physico-chemical regime of these highly stratified, dynamic salt-wedge systems is at risk in the near future from demonstrable, ongoing, compounding and often intensifying, multiple threats, such as permanent oceanic breaching, permanent mouth opening or closure (natural or artificial), significant water extraction or diversion that may cause marinisation and replacement of obligate estuarine biota with coastal marine species. The nature of its restricted geographic distribution makes it likely that the action of a threatening process could cause the ecological community to be lost in the near future. It is therefore **eligible** for listing as **Endangered** under Criterion 2.

Criterion 3 – *Loss or decline of functionally important species*

There has been significant decline or loss of keystone species within the ecological community (see Criterion 4) over the past 10 to 20 years. For example, the ecosystem engineer *Zostera muelleri* and the calanoid copepod *Gippslandia estuarina* have become almost locally extinct in the Hopkins River estuary. However there are currently insufficient data to determine the level of loss or decline of these functionally important species across the range of the ecological community. Therefore, for the purposes of the current assessment, there is **insufficient information** to determine the eligibility of the ecological community for listing under this criterion.

Criterion 4 – *Reduction in community integrity*

The combined impact of multiple and cumulative threats (in particular climate change, agricultural/urban development, water extraction, and pathogens) have reduced the integrity of the ecological community through:

- Disruption or loss of natural salt-wedge dynamics, primarily loss or decline in the typical hydrological cycle of salt-wedge; decline in functional intermittent mouth condition; and loss of connectivity between the estuary and the ocean and/or the estuary and the river and associated riparian and wetland floodplains.
- Declining water quality, including changes to temperature, oxygen levels, eutrophication sedimentation and algal blooms.
- Loss of keystone biodiversity and related function, including secondary producers (i.e. estuarine calanoid copepods), larval fish prey and ecosystem engineers (i.e. seagrass beds).
- Decline or loss of fish spawning cues and habitat, and compromised survival of estuarine fish larvae.
- Infection of copepods by 'new' viral pathogens.

These reductions in integrity have impaired the resilience and function of the ecological community across its entire range. This is expected to further exacerbate the continued and combined impacts of the various threats. Of particular concern are the disruption to salt-wedge dynamics; the loss of keystone and ecosystem engineer species; and widespread pathogen infection.

The Committee considers that the change in integrity experienced by the ecological community is substantial and restoration across its extent is unlikely in the medium-term future. Therefore, the ecological community is eligible for listing as **Vulnerable** under this criterion.

Criterion 5 – *Rate of continuing detrimental change*

The ecological community is susceptible to a variety of significant threats, with the impacts from climate change being the most consistent and demonstrable threat across all 25 estuaries. Sea level rise and increasing air and water temperature, as a consequence of climate change, are key drivers for many of the other environmental threats, such as reduced freshwater inflows, water quality and pathogens, that continue to disrupt ecological processes.

The rate of continuing detrimental change in the ecological community is substantial as indicated by the serious intensification in the disruption of key drivers of important community processes, i.e. salt-wedge dynamics, salinity stratification, salinity regime and mouth condition. In light of the substantial rate of continuing detrimental change of the two key climate change impacts, rising sea level and rising temperature, and their projected continuing change, the ecological community is eligible for listing as **Vulnerable** under this criterion.

Criterion 6 – *Quantitative analysis showing probability of extinction*

There are no quantitative data available to assess this ecological community under this criterion. Therefore, there is **insufficient information** to determine the eligibility of the ecological community for listing under this criterion.

5.2. Recommendation on recovery plan

A Recovery Plan is not recommended at this time because the Conservation Advice sufficiently outlines the priority research and conservation actions needed for the Assemblages of species associated with open-coast salt-wedge estuaries of western and central Victoria ecological community. There are also a number of existing documents, including management plans, for conservation and threat abatement that support these recovery actions. Additionally, the Estuary Entrance Management Support System (EEMSS 2007) is used to advise the Victorian government of all risks to assets and natural resources associated with opening an estuary artificially. The listing of the ecological community is not expected to impact these current established estuary management arrangements but should assist with future management planning and implementation.

The benefits of listing the ecological community and implementation of the recovery and threat abatement priorities and actions are specified in this Conservation Advice. It is recommended that the priority research and conservation actions in the Conservation Advice and this decision be considered for review within five years, after evaluating the effectiveness and completeness of the actions.

6. PRIORITY RESEARCH AND CONSERVATION ACTIONS

Conservation objective

The conservation objective is to mitigate the risk of extinction of the Salt-wedge Estuaries ecological community, assist recovery and maintain its biodiversity and function.

The four key approaches to achieve the conservation objective are:

- PROTECT the ecological community to prevent further loss of extent and condition.
- RESTORE the ecological community within its original range by active abatement of threats and other conservation initiatives.
- COMMUNICATE, ENGAGE WITH AND SUPPORT researchers, CMAs, land and water managers, land use planners, landholders and community members, including the Indigenous community, to increase understanding of the value and function of the ecological community and encourage their efforts in its protection and recovery.
- RESEARCH AND MONITORING to improve our understanding of the ecological community and the best methods to aid its management and recovery.

In assessment of activities that may have a significant impact on the ecological community, the relevant actions listed below should be considered when determining recommendations, including conditions of approval. Applications to Australian Government funding programs should consider prioritising the research and restorative activities that work toward a healthy and sustainable ecological community.

6.1. Priority protection, conservation management and recovery actions

Priority actions are recommended for the abatement of threats and to support recovery and rehabilitation (where appropriate) of the ecological community. Actions inconsistent with these recommendations that are likely to significantly affect the ecological community should be avoided.

6.1.1. Protect

Climate Change

- Enhance the resilience of the ecological community to the impacts of climate change by reducing other pressures.

Land use and associated decline in water quality

- Prevent impacts to native vegetation, fauna and substrate from any actions within, adjacent to or near the ecological community by planning for, avoiding or mitigating off-site impacts. Apply recommended buffers around the ecological community and avoid activities that could cause significant change to hydrology or water quality e.g. dredging, deposition of spoil, aquaculture facilities or major construction projects such as marinas. Wider buffers may be required where there is larger scale landscape change. Where possible, protect the inundation area of the estuaries by targeted land purchases.

Modification of flow regime

- Establish baseline mouth closure frequency and duration data for all estuaries within the community (see research priorities below).

- Maintain the natural, three phase flow regime required for salt-wedge dynamics by allowing estuary mouths to remain open at frequencies, for durations, and with passing flows, sufficient to maintain natural or typical hydrological regimes (see Figure C1). The EEMSS (2007) should be used to provide guidance on artificial opening of estuary mouths.
- Ensure that surface water and ground water extraction, major riverine regulatory infrastructure (e.g. reservoirs) and other infrastructure (e.g. bridges) do not significantly alter the current hydrology of estuaries within the ecological community.
- Ensure that catchment land-use changes do not significantly affect water quantity, quality and seasonality.
- Minimise water quality impacts caused by run-off into rivers and estuaries, including pollution, increased nutrients (leading to eutrophication), chemical contamination, turbidity and sedimentation by protecting buffer zones and implementing measures to reduce erosion within river catchments.
- Undertake risk assessments to identify areas of potential and active acid sulphate soils and develop and implement strategies to mitigate and manage acid flows.

Invasive species

- Eradicate or manage threatening weed infestations, such as willows, associated with riparian and adjacent wetland vegetation using appropriate methods.
- Ensure that chemicals or other mechanisms used to eradicate weeds in the surrounding landscape do not have adverse impacts on the ecological community.

Disease (pathogens and parasites)

- Minimise outbreaks of viruses (e.g. iridovirus in copepods) and fungal disease (e.g. Epizootic Ulcerative Syndrome or Red Spot Disease in fish) within the ecological community by maintaining optimum water quality and reducing other disturbance pressures.

6.1.2. Restore

- Implement appropriate management to improve water quality and restore natural or typical river flows with seasonal high and low flow cycles that support the periodic seasonal salt-wedge flushing and formation to build resilience of the ecological community and facilitate ecological function.
- Undertake restoration of riparian and buffer zones, seagrass, Ruppia beds and other in-stream habitat areas (including low-flow refuges) where they have been degraded or lost.
- In conjunction with appropriate research and monitoring, consider reintroduction of lost or depleted biota, including keystone species.

6.1.3. Communication and engagement

Education, information and local regulation

- Develop a communication strategy, education programs, information products and signage to help local communities, planners and managers recognise:
  - when the ecological community is present and why it is important to protect it;

- how to appropriately support and manage the ecological community to enhance its biodiversity and ecology, including responsible management of the estuary mouth; and
- responsibilities under state and local regulations and the EPBC Act.

- Promote knowledge about deoxygenation, blackwater events and fish kills, including how these events impact the ecological community and strategies to mitigate these impacts (recognising that these events can also occur naturally).
- Promote awareness and protection of the ecological community with relevant agencies and industries. For example with:
  - State and local government planning authorities (such as CMAs), to ensure that planning takes the protection of rivers and estuaries into account, with due regard to principles for long-term conservation.
  - Community groups, such as EstuaryWatch. EstuaryWatch groups meet regularly. Monitors take photos of the estuary mouth, record water level (AHD) and conduct water quality monitoring. This data is available to the public at www.estuarywatch.org.au (CCMA 2017b).
  - Local councils and state authorities, to ensure water extraction, riverine regulatory infrastructure and actions undertaken within or adjacent to the ecological community, do not adversely impact the ecological community.
  - Landholders and farmers, to minimise water quality impacts from agricultural land use, such as pollution from chemicals and fertilisers, increased turbidity from erosion and altered hydrology.
  - Recreational fishers and fishing industry, to ensure that fishing practices do not adversely impact the ecological community.

Incentives and support

- Support opportunities for traditional owners or other members of the Indigenous community to engage with and manage the ecological community.
- Encourage local participation in recovery efforts (e.g. revegetation of seagrass beds and riparian zones), removing threats and actively maintaining the ecological community. Support on-ground action and integrated management for invasive flora and fauna.
- Develop coordinated incentive projects to encourage conservation and stewardship on adjacent private land and those with significant tributaries flowing into the ecological community and link with other programs and activities, especially those managed by regional catchment councils.

6.2. Monitoring and research priorities

Targeted research, monitoring and relevant community-based programs are required to inform the protection and management of the ecological community. The efforts of individuals and groups with responsibilities for planning, on-ground management and data collection should be coordinated so that results can be applied across the various estuarine systems within the ecological community. A centralised repository or shared data warehouse arrangement would facilitate this approach.

Citizen scientists, such as EstuaryWatch groups, can play an important role in collecting long term data on the condition of the estuaries. Having citizen scientists involved could increase the amount of data collection, foster stewardship at each estuary and facilitate knowledge sharing between estuary managers, researchers and community. The data produced can inform about the length of time estuaries are open to the sea and can track the three phase flow regime required for salt-wedge dynamics (CCMA 2017b).

High priority monitoring and research activities to inform protection, conservation, adaptive management and restoration of the ecological community include, but are not limited to, the following:

Monitoring

- Install telemetry stations in estuaries that do not already have them installed to regularly capture profiles and surface measurements of physico-chemical parameters.
- Undertake regular analysis of physicochemical data from estuaries within the ecological community to determine trends and opportunities to improve water quality and build resilience of the ecological community to ongoing threats.
- Record and make available both discharge data and water extraction data for each estuary in the ecological community.
- Monitor and record occurrences of algal blooms, blackwater events, acid flows and fish kills in a centralised database.
- Monitor and record incursions of invasive species (including, but not limited to fish) across the ecological community.
- Support the implementation of the Index of Estuary Condition and its application to the ecological community.
- Undertake periodic surveys of seagrass and other macrophytes across the ecological community to assess their status.
- Undertake surveys and monitoring of the composition of pelagic flora and fauna in representative estuaries across the distribution of the ecological community.
- Undertake surveys to quantify recreational catches of native fish species within the ecological community to determine whether management actions are required.
- Monitor changes in condition, including response to all types of management actions and use this information to increase understanding of the ecological community and inform recommendations for future management.

Research

- Undertake baseline assessments of a representative sub-set of the community to clarify the ecological composition of the community. Include identification of local invasive and problematic native species.
- Gain a greater understanding of estuary mouth dynamics in relation to natural opening and closing behaviour versus artificial opening of the estuaries, including regular, long-term recording and analysis of related data.

- Establish environmental flow requirements for each system and ensure this informs future water resource plans.
- Continue to build an understanding of the biotic variation in the ecological community.
- Continue to investigate the threat of disease in the ecological community, including iridovirus infection in mesozooplankton. Determine which estuaries are affected, and if possible, identify causal factors and preventative measures. Determine the levels of impact of disease on secondary productivity, food web dynamics and estuarine fish recruitment.
- Develop control methods to reduce or eradicate invasive fish species in the estuaries and parent river systems of the ecological community. Undertake trials to assess effectiveness and appropriateness of control methods prior to implementation.
- Investigate the disappearance of significant coverage of seagrass and macrophytes where these are known to occur (e.g. Hopkins estuary).
- Continue to build an understanding of the risks associated with climate change, including sea level rise, increasing temperature, ocean acidification and future flood risk.
- Assess the vulnerability of the ecological community to climate change and long-term drought, and investigate ways to improve resilience through threat abatement and management actions.
- Determine the importance of groundwater inflow to the ecological community, particularly with regard to freshwater discharge.

6.3. Offsets

Offsets are defined as measures that aim to compensate for the residual adverse impacts of an action on the environment. Further damage to the ecological community should not occur. As the ecological outcomes of offsetting activities are generally uncertain, offsetting should only be proposed as an attempt to compensate for damage to the ecological community that is deemed unavoidable. Areas that already meet the key diagnostic characteristics are protected by this listing, so are not to be used as an offset unless there is a substantial net benefit. With regard to any proposed actions involving offsets for the Salt-wedge Estuaries ecological community, the aims are to:

- Ensure that offsets are consistent with the wording and intent of the EPBC Act Environmental Offsets Policy (Commonwealth of Australia 2012), including:
    - ‘like-for-like’ principles based on meeting the overall definition of the ecological community and considering the particular species composition and other habitat and landscape features at a particular site; and
    - how proposed offsets will address key priority actions outlined in this Conservation Advice and any other relevant recovery plans, threat abatement plans and any other Commonwealth management plans.
- Maintain (or increase) the overall quality and ecological function of the remaining extent of the ecological community and surrounding catchments and improve formal protection through a combination of the following measures:

- placement of areas of the ecological community and adjacent mature vegetation in formal reserve tenure or other conservation-related land tenure for protection and management in perpetuity; and/or
- improve the condition and ecological function of salt-wedge estuaries, for example, by enhancing riverine water quality and riparian zone condition, to ensure that any offset sites add additional value to the remaining extent.

6.4. Existing plans/management prescriptions relevant to the ecological community

There is no approved state recovery plan for the ecological community as defined in this listing. However, management prescriptions exist in the form of estuary management plans for individual estuaries. A list of these plans is at Appendix B6.

APPENDICES

APPENDIX A: IMPORTANT AND FREQUENTLY OCCURRING BIOTA WITHIN THE ECOLOGICAL COMMUNITY

Table A1: Taxonomic list of phytoplankton and protists from the Hopkins River estuary (adopted from Rouse 1998).

Phylum Dinophyta (Dinoflagellates)	**Genus *Paralia***
Genus *Amphidinium*	cf. *Paralia* sp. 1
Amphidinium sp.	cf. *Paralia* sp. 2
Genus *Alexandrium*	**Genus *Petroneis***
Alexandrium cf. *minutum*	*Petroneis* cf. *marina*
Genus *Dinophysis*	**Genus *Pinnunavis***
Dinophysis acuminata	*Pinnunavis yarrensis*
Dinophysis cf. *caudata*	**Genus *Pleurosigma***
Genus *Ebria*	*Pleurosigma* cf. *fluviicygnorum*
Ebria iripartita	**Genus *Pseudo-nitzschia***
Genus *Prorocentrum*	*Pseudo-nitzschia pungens*
Prorocentrum minimum	**Genus *Rhizosolenia***
Uncertain dinoflagellate taxa	*Rhizosolenia setigera*
Oxyrrhis marina	**Genus *Rhopalodia***
Phylum Bacillariophyta (Diatoms)	*Rhopalodia* cf. *gibberula*
Genus *Achnanthes*	*Rhopalodia* sp. 1
Achnanthes brevipes	**Genus *Seminavis***
Achnanthes sp. 1	*Seminavis* cf. *ventricosa*
Genus *Amphora*	**Genus *Surirella***
Amphora sp. 1	*Surirella* sp. 1
Genus *Bacillaria*	*Sirirella* sp. 2
Bacillaria paxillifera	**Genus *Thalassionema***
Genus *Caloneis*	cf. *Thalassionema nitzschioides*
Caloneis cf. *brevis*	**Genus *Thalassiosira***
Genus *Campyloneis*	*Thalassiosira* cf. *eccentrica*
cf. *Campyloneis* sp. 1	*Thalassiosira lacustris*
Genus *Cerataulina*	
Cerataulina pelagica	**Genus *Tryblionella***
Genus *Chaetoceros*	*Tryblionella* cf. *hungarica*
Chaetoceros lorenzianus	**Phylum Prymnesiophyta (Prymnesiophytes)**
Genus *Cocconeis*	**(=Haptophyta/Haptophytes)**
Cocconeis scutellum var. *parva*	**Genus *Pleurochrysis***
Genus *Conticriba*	*Pleurochrysis carterae*
Conticriba weissflogii	**Ciliates**
Genus *Ctenophora*	Genus *Coleps*
Ctenophora pulchella	Genus *Condylostoma*
Genus Cyclotella	Genus *Cristigera*
Cyclotella meneghiniana	Genus *Frontonia*
Genus *Diploneis*	Genus *Plagiopogon*
Diploneis cf. *smithii* var. *rhombica*	Genus *Plagiopyla*
Diploneis cf. *subovalis*	Genus *Prorodon*
Diploneis cf. *didyma*	Genus *Sonderia*
Genus *Entomoneis*	Genus *Tracheloraphis*
Entomoneis cf. *tenuistriata*	Genus *Urotricha*
Genus *Gyrosigma*	**Freshwater Protista**
Gyrosigma cf. *fasciola*	**Chlorophyta**
Gyrosigma cf. *turgidum*	Genus *Ankistrodesmus*
Gyrosigma cf. *spenceri*	Genus *Binuclearia*
Gyrosigma cf. *balticum*	Genus *Botryococcus*
Gyrosigma cf. *formosum*	Genus *Oocystis*
Genus *Halamphora*	Genus *Scenedesmus*
Halamphora holsatica	Genus *Staurastrum*
Genus *Hantzschia*	**Chrysophyta**
Hantzschia cf. *virgata*	Genus *Mallomonas*
Genus *Hyalodiscus*	Genus *Synura*
Hyalodiscus cf. *lentiginosus*	

Genus *Lyrella* *Lyrella lyra* **Genus *Melosira*** *Melosira octogona* *Melosira* sp. 1 *Melosira* sp. 2 cf. *Melosira* sp. 1 **Genus *Navicula*** *Navicula* cf. *clamans* *Navicula (Fallacia)* cf. *florinae* *Navicula* cf. *granulata* cf. *Navicula* sp. 1 **Genus *Neidium*** *Neidium* cf. *productum* **Genus *Nitzschia*** *Nitzschia* cf. *scalpelliformis* **Genus *Odontella*** *Odontella* cf. *laevis*	**Photosynthetic bacteria** cf. *Chromatium* sp.

Table A2: Systematic Scheme - Hopkins River estuary zooplankton, 1983-1985 (Newton 1994) (Note, indet. = indeterminate identification).

PROTOZOA	Sarcomastogophora	Foraminiferida	indet. foraminiferans
	Ciliophora	Tintinnida	indet. tintinnids
COELENTERATA	Hydrozoa	Limnomedusae	*Australomedusa baylii*
			indet. medusa
CTENOPHORA			indet. ctenophores
PLATYHELMINTHES	Turbullaria	Digenea	furcocercous cercaria larvae
NEMERTINEA			pilidium larvae
NEMATODA			indet. nematodes
KINORHYNCHA			cf. *Pycnophyes* sp.
ROTIFERA		Asplanchnidae	Asplanchna cf. *bightwelli*
		Brachionidae	*Brachionus angularis*
			B. cf. *budapestinensis*
			B. nilsoni
			B. novaezealandiae
			B. plicatilis
			B. quadrientatus melheni
			indet. *Brachionus* spp.
			Keratella australis
			K. procurva
			K. cf. *quadrata*
			K. shieli
			K. slacki
			K. cf. *valga*
			indet. *Keratella* spp.
			Notholca cf. *squamula*
		Epiphanidae	*Epiphanes* sp.
		Filiniidae	*Filinia longiseta*
		Lecanidae	*Lecane ohioensis* f. *ichthyoura*
		Mytilinidae	*Lophocharis salpina*
		Synchaetidae	cf. *Synchaeta* sp.
		Testudinellidae	*Pompholyx* sp.
		Trichocercidae	*Trichocerca* cf. *bicristata*
			indet. rotifers
ANNELIDA	Polychaeta		indet. trochophores
			indet. larvae
			Nereid sp?
	Oligochaeta	Naididae?	indet. sp.
MOLLUSCA	Bivalvia	Lamellibranchia	indet. larvae
	Gastropoda	Prosobranchia	indet. larvae
ARTHROPODA			
-CRUSTACEA	Cladocera	Bosminidae	*Bosmina meridionalis*
		Chydoridae	*Alona* cf. *rectangula*
			Coronatella rectangula novaezealandiae
			Karualona karua
			Camptocercus australis
			Chydorus sp.
			Pleuroxus cf. *inermis*
			indet. spp.
		Daphniidae	*Daphnia carinata*
			D. lumholtzi
	Ostracoda		*Paracypria* sp.
			Sarscypridopsis sp.
			indet. spp.
	COPEPODA		
	-Calanoida	Acartiidae	*Acartia tranteri*
		Centropagidae	*Boeckella triarticulata*
			Calamoecia ampulla
			C. gibbosa
			Centropages australiensis
			Gippslandia estuarina
			Gladioferens pectinatus
			Isias uncipes
		Paracalanidae	*Bestiolina similis*

Table A2 (continued): Systematic Scheme - Hopkins River estuary zooplankton.

			Paracalanus indicus
		Sulcanidae	*Sulcanus conflictus*
	-Cyclopoida	Ergasilidae	*Ergasilus australiensis*
			E. lizae
			Ergasilus sp. nov.
		Cyclopidae	*Eucyclops* sp. nov.
			Halicyclops sp.
			Macrocyclops albidus
			Metacyclops sp. nov.
			Paracyclops chiltoni
		Oithonidae	*Oithona rigida*
			O. similis
		?	indet. semi-parasitic sp. A
	-Harpacticoida	Ameridae	gen. nov. sp. nov.
			indet. spp.
		Canthocamptidae	*Attheyella australicus*
			A. hirsutus
			Epactophanes richardi
			Mesochra parva
			Mesochra sp. A
			Mesochra sp. B
		Canuellidae	indet. sp.
		Cletodidae	*Australonannopus aestuarinus*
			indet. sp.
		Darcythompsoniidae	gen. nov. sp. nov.
		Diosaccidae	*Amphiascoides* sp. nov.
			Miscegenus sp.
			Robertgurneya sp.
			Schizopera sp.
			Stenhelia sp.
			indet. spp.
		Ectinosomatidae	sp. 1
			sp. 2
			sp. 3
			Microsetella rosea
		Harpacticidae	*Zausopsis mirabilis*
			cf. *Zausopsis* cf. *luederitzi*
			indet. sp.
		Laophontidae	*Folioquinpes chathamensis*
			indet. sp.
		Peltidiidae	indet. spp.
		Phyllognathopodidae	*Phyllognathopus* sp.
		Tachidiidae	*Euterpina acutifrons*
		Thalestridae	indet. sp.
		Tisbidae	*Scutellidium* sp.
			Tisbe sp.
	Isopoda		indet. isopods
	Amphipoda	Calliopidae	*Paracalliope* sp.
		Corophiidae	*Megamphopus* sp.
			Photis sp.
		Eusiridae	*Tethygenia* cf. *waminda*
		Hyperidea	indet. sp.
			indet. amphipods
	Mysidacea	Mysidae	*Tenagomysis* sp.
	Cumacea	Diastylidae	*Dimorphostylis colefaxi*
	Cirripedia		indet. cypris larvae
	DECAPODA		
	Brachyura	Grapsidae	cf. *Helograpsus haswellianus*
			indet. spp.
		Hymenosomatidae	*Amarinus laevis*
			A. paralacustris

Table A2 (continued): Systematic Scheme - Hopkins River estuary zooplankton.

			Elamena or *Trigonoplax* sp.
	Caridea	Atyidae	*Paratya australiensis*
		Palemonidae	*Palaemon intermedius*
	Penaeidea		*Lucifer hanseni*
	Thalassinidea	Callianassidae	*Callianassa* sp.
			indet. pandalid/hypolytid
-INSECTA			
	Diptera		chironomid larvae
	Collembola		springtails
	Ephemeroptera		may-fly larvae
-ARACHNIDA	Hydracarina		indet. mites
BRYOZOA			cyphonautes larvae
CHORDATA			
-UROCHORDATA	Larvacea		*Oikopleura dioica*
-VERTEBRATA	Teleosti (larvae)	cf. Atherinidae	indet. larvae
		cf. Clinidae	indet. larvae
		Eleotridae	cf. *Philypnodon grandiceps* (larvae type C)
		Engraulididae	*Engraulis australis* (eggs and larvae)
		Galaxidae	*Galaxius maculatus* (juvenile)
		Gobiidae	type A1 cf. *Pseudogobius olorum* larvae
			type A2 cf. *Arenigobius bifrinatus* larvae
			type B cf. *Favonigobius tamarensis* larvae
		Percichthyidae	*Macquaria colonorum* (eggs and larvae)
		Sparidae	*Acanthopagrus butcheri* (eggs and larvae)
		cf. Tetraodontidae	indet. larvae
		cf. Tripterygiidae	indet. larvae

Table A3: Fish recorded in the Gellibrand, Hopkins, Glenelg and Surry estuaries (after Koehn & O'Connor 1990; Newton 1994; Barton & Sherwood 2004; Becker 2007; Lloyd et al. 2008; WGCMA 2015; GHCMA 2006b).

Estuary Fish Group	Sub-Types	Common Name	Taxonomic Name
Estuarine Residents	n/a	black bream [C,R]	*Acanthopagrus butcheri*
		bluespot goby	*Pseudogobius olorum*
		bridled goby	*Arenigobius bifrenatus*
		estuary perch [C,R]	*Macquaria colonorum*
		flat-headed gudgeon	*Philypnodon grandiceps*
		half bridled goby	*Arenigobius frenatus*
		Scary's tasman goby	*Tasmanogobius lasti*
		southern longfin goby	*Favonigobius lateralis*
		Tamar goby	*Afurcagobius tamarensis*
Estuarine Dependent	Marine Derived (Anadromous)	congolli (tupong) [C,R]	*Pseudaphritis urvillii*
		elongate hardyhead	*Atherinosoma elongata*
		King George whiting [C,R]	*Sillaginodes punctata*
		mulloway [C,R]	*Argyrosomus japonicas*
		pikehead hardyhead	*Kestratherina esox*
		pouched lamprey	*Geotria australis*
		shortheaded lamprey	*Mordacia mordax*
		silver fish	*Leptatherina presbyteroides*
		smallmouth hardyhead	*Atherinosoma microstoma*
	Freshwater Derived (Catadromous)	Australian grayling[#]	*Prototroctes maraena*
		climbing galaxias	*Galaxias brevipinnis*
		common galaxias (jollytail)	*Galaxias maculatus*
		eastern dwarf galaxias	*Galaxiella pusilla*
		shortfinned eel [C,R]	*Anguilla australis*
		spotted galaxias	*Galaxias truttaceus*
		Tasmanian mudfish	*Neochanna cleaveri*
Estuarine Opportunists/ Strays	Marine Derived (Anadromous)	anchovy	*Engraulis australis*
		bearded red cod	*Pseudophycis barbata*
		blue morwong [C,R]	*Nemadactylus valenciennesi*
		blue sprat [C,R]	*Spratelloides robustus*
		bluethroat wrasse	*Notolabrus tetricus*
		dusky flathead [C,R]	*Platycephalus fuscus*
		dusky morwong	*Dactylophora nigricans*
		eastern Australian salmon [C,R]	*Arripis trutta*
		eastern fortesque	*Centropogon australis*
		globefish	*Diodon nicthemerus*
		greenback flounder [C,R]	*Rhombosolea tapirina*
		knifesnout pipefish	*Hypselognathus rostratus*
		little weed whiting	*Neoodax balteatus*
		longsnout flounder [C,R]	*Ammotretis rostratus*
		luderick [C,R]	*Girella tricuspidata*
		old wife	*Enoplosus armatus*
		pilchard [C]	*Sardinops sagax*
		prickly toadfish	*Contusus brevicaudus*
		red gurnard	*Chelidonichthys kumu*
		sand flathead [C,R]	*Platycephalus bassensis*
		sand mullet	*Myxus elongatus*
		sandy sprat	*Hyperlophus vittatus*
		sea mullet [C,R]	*Mugil cephalus*
		silver morwong [C,R]	*Nemadactylus douglasii*
		silver trevally [C,R]	*Pseudocaranx dentex*
		sixspine leatherjacket [C,R]	*Meuschenia freycineti*
		skipjack trevally [C,R]	*Pseudocaranx wrighti*
		smooth toadfish	*Tetractenos glaber*
		snapper [C,R]	*Chrysophrys auratus*
		soldier	*Gymnapistes marmoratus*
		southern bluespotted flathead [C,R]	*Platycephalus speculator*
		southern fiddler ray	*Trygonorrhina dumerilii*
		southern pygmy leatherjacket	*Brachaluteres jacksonianus*
		southern red scorpionfish	*Scorpaena papillosa*
		southern sea garfish	*Hyporhamphus melanochir*

		spotted pipefish tailor [C,R] tommy ruff [C,R] toothbrush leatherjacket western Australian salmon widebody pipefish yellow-eye mullet [C,R] yellowfin goby (alien fish species)	*Stigmatopora argus* *Pomatomus saltatrix* *Arripis georgianus* *Acanthaluteres vittiger* *Arripis truttaceus* *Stigmatopora nigra* *Aldrichetta forsteri* *Acanthogobius flavimanus*
	Freshwater Derived (Catadromous)	Australian smelt river blackfish [R] southern pygmy perch variegated pygmy perch western carp gudgeon Yarra pygmy perch	*Retropinna semoni* *Gadopsis marmoratus* *Nannoperca australis* *Nannoperca variegata* *Hypseleotris klunzingeri* *Nannoperca obscura*
Not the ecological community (alien species)	Freshwater Derived (Catadromous)	brown trout [R] (alien fish species) gambusia (alien fish species) rainbow trout [R] (alien fish species) redfin (alien fish species) roach (alien fish species) tench (alien fish species)	*Salmo trutta* *Gambusia holbrooki* *Oncorhynchus mykiss* *Perca fluviatilis* *Rutilus rutilus* *Tinca tinca*

[#] *Australian grayling is listed as Vulnerable under the Victorian FFG Act and the Australian Government's EPBC Act*
[C] *These species have commercial fisheries value*
[R] *These species have recreational fisheries value*

APPENDIX B: DETAILS OF NATIONAL CONTEXT

B1: Bioregional distribution

Table B1: IBRA bioregions and subregions of the ecological community.

Estuary	Bioregion	Subregion
Glenelg River	Naracoorte Coastal Plain	Glenelg Plain
Surry River	South East Coastal Plain	Warrnambool Plain
Fitzroy River	South East Coastal Plain	Warrnambool Plain
Eumeralla River	South East Coastal Plain	Warrnambool Plain
Merri River	South East Coastal Plain	Warrnambool Plain
Hopkins River	South East Coastal Plain	Warrnambool Plain
Curdies River	South East Coastal Plain	Warrnambool Plain
Sherbrook River	South East Coastal Plain	Warrnambool Plain
Gellibrand River	South East Coastal Plain	Warrnambool Plain
Johanna River	South East Coastal Plain	Otway Plain
Aire River	South East Coastal Plain	Otway Plain
Barham River	South East Coastal Plain	Otway Plain
Kennett River	South Eastern Highlands	Otway Ranges
Wye River	South Eastern Highlands	Otway Ranges
St George River	South Eastern Highlands	Otway Ranges
Erskine River	South Eastern Highlands	Otway Ranges
Painkalac Creek	South East Coastal Plain	Otway Plain
Anglesea River	South East Coastal Plain	Otway Plain
Spring Creek	South East Coastal Plain	Otway Plain
Thompson Creek	South East Coastal Plain	Otway Plain
Powlett River	South East Coastal Plain	Gippsland Plain
Darby River	South East Coastal Plain	Gippsland Plain
Tidal River	Flinders	Wilsons Promontory
Growler Creek	Flinders	Wilsons Promontory

B2: Other existing protection

Table B2: National and state protected areas for the ecological community (adopted from Parks Victoria 2017).

Estuary	Protected land areas	Protected marine areas
Growlers Creek	Wilsons Promontory National Park (Southern Wilsons Promontory Remote and Natural Area)	Wilsons Promontory Marine National Park
Tidal River	Wilsons Promontory National Park	Wilsons Promontory Marine Park
Darby River	Wilsons Promontory National Park (Southern Wilsons Promontory Remote and Natural Area)	Wilsons Promontory Marine Park
Powlett River	Kilcunda Nature Conservation Reserve	Kilcunda – Hamers Haven Coastal Reserve
Thompson Creek	Breamlea Flora and Fauna Reserve	-
Spring Creek	-	-
Anglesea River	-	-
Painkalac Creek	-	Eagle Rock Marine Sanctuary
Erskine River	-	-
St George River	Great Otway National Park	-
Wye River	Great Otway National Park	-
Kennett River	Great Otway National Park	-
Barham River	Barham Paradise Scenic Reserve	-
Aire River	Great Otway National Park Aire River Wildlife Reserve	-
Johanna River	Great Otway National Park	-
Gellibrand River	Great Otway National Park Port Campbell National Park Princetown Wildlife Reserve	Twelve Apostles Marine National Park
Sherbrook River	Port Campbell National Park	-
Port Campbell Creek	Port Campbell National Park	-
Curdies River	Port Campbell National Park	-
Hopkins River	-	-
Merri River	-	Merri Marine Sanctuary
Eumeralla River (Lake Yambuk)	Deen Maar Indigenous Protected Area Yambuk Wetlands Nature Conservation Reserve Eumeralla (Yambuk Coastal Reserve)	Eumeralla (Yambuk Coastal Reserve)
Fitzroy River	Fitzroy River streamside Reserve Narrawong Coastal Reserve Tyrendarra Flora Reserve Tyrendarra Indigenous Protected Area	-
Surry River	Narrawong Coastal Reserve	Narrawong Coastal Reserve
Glenelg River	Discovery Bay Coastal Park (VIC) Lower Glenelg National Park (VIC) Lower Glenelg River Conservation Park (SA) Glenelg River Streamside Reserve Nelson Streamside Reserve Glenelg Estuary and Discovery Bay Ramsar site	-

B3: Relationship to state listed vegetation classifications

Table B3. Bioregional conservation status (as at 2007) for two EVCs that best correspond to the ecological community (DSE 2007).

Victorian bioregion	Bioregional conservation status	
	EVC 9 Coastal saltmarsh	**EVC 10 Estuarine wetland**
Glenelg Plain	n/a	n/a
Warrnambool Plain	n/a	Depleted
Otway Ranges	n/a	Endangered
Otway Plain	Endangered	Endangered
Gippsland Plain	Least concern	Least concern
Wilsons Promontory	Least concern	Rare

B4: Nationally threatened species likely to occur in or near the ecological community

Table B4: Nationally threatened flora and fauna species that have been observed, or are likely to occur, in or near the ecological community (as at August 2017) (DEE 2017).

[Known occurrences of some species may be in landscapes or vegetation communities or in offshore regions nearby to the ecological community].

Taxon	**Common name**	**EPBC Act listing**	**Victorian listing**
Birds			
Botaurus poiciloptilus	Australasian bittern	E	Threatened
Calidris ferruginea	curlew sandpiper	CE	E (Advisory List 2013)
Calidris tenuirostris	great knot	CE	Threatened
Charadrius mongolus	lesser sand plover	E	CE (Advisory List 2013)
Limosa lapponica baueri	bar-tailed godwit (baueri)	V	-
Neophema chrysogaster	orange-bellied parrot	CE	Threatened
Numenius madagascariensis	eastern curlew	CE	V (Advisory List 2013)
Rostratula australis	Australian painted snipe	E	Threatened
Sternula nereis nereis	fairy tern (Australian)	V	Threatened
Thinornis rubricollis rubricollis	hooded plover (eastern)	V	V (Advisory List 2013)
Mammals			
Antechinus minimus maritimus	swamp antechinus (coastal Victoria and far south-eastern South Australia)	V	Threatened
Mastocomys fuscus mordicus	broad-toothed rat (mainland)	V	-
Miniopterus orianae bassanii	southern bent-wing bat	CE	Threatened
Potorous tridactylus tridactylus	long-nosed potoroo (SE mainland)	V	Threatened
Pseudomys novaehollandiae	New Holland mouse	V	Threatened
Macroinvertebrates			
Euastacus bispinosus	Glenelg spiny freshwater crayfish	E	Threatened
Sharks			
Carcharodon carcharias	white shark	V	Threatened
Fish			
Galaxiella pusilla	eastern dwarf galaxias	V	Threatened
Prototroctes maraena	Australian grayling	V	Threatened
Amphibians			
Litoria raniformis	southern bell frog	V	Threatened
Plants			
Caladenia orientalis	eastern spider orchid	E	Threatened
Haloragis exalata subsp. *exalata*	wingless raspwort	V	V (Advisory List 2014)
Prasophyllum frenchii	maroon leek-orchid	E	Threatened
Prasophyllum spicatum	dense leek-orchid	V	E (Advisory List 2014)
Pterostylis cucullata	leafy greenhood	V	Threatened
Pterostylis tenuissima	swamp greenhood	V	V (Advisory List 2013)
Senecio psilocarpus	swamp fireweed	V	V (Advisory List 2014)
Xerochrysum palustre	swamp everlasting	V	Threatened

CE – Critically Endangered

E - Endangered

V - Vulnerable

B5: Birds under international agreements

As a party to the Bonn Convention, Australia has agreed to protect migratory species and to negotiate and implement agreements for the conservation and management of migratory species with other range states, including cooperation and support of research relating to migratory species:

- the agreement between the Government of Australia and the Government of Japan for the Protection of Migratory Birds in Danger of Extinction and their Environment 1974 (JAMBA)
- the agreement between the Government of Australia and the Government of the People's Republic of China for the Protection of Migratory Birds in Danger of Extinction and their Environment 1986 (CAMBA), and
- the agreement between the Government of Australia and the Government of the Republic of Korea for the Protection of Migratory Birds 2007 (ROKAMBA).

The Salt-wedge Estuaries ecological community provides critical habitat for several wetland and coastal water birds that are listed under these various international agreements (DEE 2017).

Table: B5: Migratory bird species that have been observed, or are likely to occur, in the ecological community or the riparian zone (DEE 2017, Vic SAC 2017) include:

Actitis hypoleucos (common sandpiper)	*Limicola falcinellus* (broad-billed sandpiper)
Ardenna tenuirostris (short-tailed shearwater)	*Limosa lapponica* (bar-tailed godwit)
Arenaria interpres (ruddy turnstone)	*Limosa limosa* (black-tailed godwit)
Apus pacificus (fork-tailed swift)	*Myiagra cyanoleuca* (satin flycatcher)
Ardenna carneipes (flesh-footed shearwater)	*Numenius madagascariensis (*eastern curlew)
Calidris acuminata (sharp-tailed sandpiper)	*Numenius minutus* (little curlew)
Calidris alba (sanderling)	*Numenius phaeopus* (whimbrel)
*Calidris canutus (r*ed knot)	*Hirundapus caudacutus* (white-throated needletail)
*Calidris ferruginea (*curlew sandpiper)	*Pandion cristatus* (eastern osprey)
Calidris melanotos (pectoral sandpiper)	*Pluvialis fulva* (Pacific golden plover)
Calidris ruficollis (red-necked stint)	*Pluvialis squatarola* (grey plover)
*Calidris tenuirostris (*great knot)	*Rhipidura rufifrons* (rufous fantail)
Charadrius bicinctus (double-banded plover)	*Sternula (Sterna) albiforns (*little tern)
Charadrius leschenaultia (greater sand plover)	*Tringa brevipes* (grey-tailed tattler)
*Charadrius mongolus (*lesser sand plover)	*Tringa stagnatilis* (marsh sandpiper, little greenshank)
*Charadrius veredus (*oriental plover)	*Tringa nebularia* (common greenshank)
Gallinago hardwickii (Latham's snipe)	*Xenus cinereus* (Terek sandpiper)
*Hydropogne (Sterna) caspia (*Caspian tern)	

B6: Existing plans/management prescriptions relevant to the ecological community

Table B6: Existing plans relevant to the ecological community (complete references available in the Bibliography at the end of this document).

Name of plan	Author
Aire River Estuary Management Plan 2015-2023	Corangamite Catchment Management Authority (2015)
Anglesea River Estuary Management Plan 2012-2020	Corangamite Catchment Management Authority (2012)
Annual climate statement 2015	Bureau of Meteorology (2016)
Central West Estuaries Coastal Action Plan 2005	Western Coastal Board (2005)
Climate Change in Australia – Projections for Australia's NRM Regions	CSIRO
Coast Adapt – Sea-level rise information for all Australian coastal councils	National Climate Change Adaption Research Facility
Corangamite Marine and Biodiversity Coastal Strategy	Corangamite Catchment Management Authority (2009)
Corangamite Native Vegetation Plan 2003-2008	Corangamite Catchment Management Authority (2005)
Corangamite Waterway Strategy 2014 – 2022	Corangamite Catchment Management Authority (2014)
Corangamite Wetland Strategy 2006 – 2011	Corangamite Catchment Management Authority (2006)
Curdies River Estuary Management Plan	Corangamite Catchment Management Authority (2016)
Data Analysis and Interpretation Gellibrand River Estuary 2007-2012	Corangamite Catchment Management Authority (2013)
Estuary Entrance Management Support System (EEMSS) database	Arundel H (2007)
Fitzroy Estuary Management Plan	Glenelg Hopkins Catchment Management Authority (2006)
Gellibrand River Estuary Management Plan	Corangamite Catchment Management Authority (2016)
Glenelg Estuary and Discovery Bay Ramsar Site Management Plan	Department of Environment, Land, Water and Planning (2017)
Glenelg Estuary Management Plan	Glenelg Hopkins Catchment Management Authority (2006)
Great Otway National park and Otway Forest Park Management Plan 2009	Parks Victoria (2009)
Hopkins Estuary Management Plan	Glenelg Hopkins Catchment Management Authority (2005)
Merri Estuary Management Plan	Glenelg Hopkins Catchment Management Authority (2008)
Painkalac Creek Estuary Management Plan	Surf Coast Shire (2004)
Port Campbell National Park and Bay of Islands Coastal Park Management Plan 1998	Parks Victoria (1998)
Powlett River Estuary Management Plan	West Gippsland Catchment Management Authority (2015)
South West Estuaries Coastal Action Plan 2002	Western Coastal Board (2002)
Surry Estuary Management Plan	Glenelg Hopkins Catchment Management Authority (2007)

Twelve Apostles Marine National Park Management Plan 2006	Parks Victoria (2006a)
Victorian Index of Estuary Condition: Recommended themes and measures	Arundel HP, Pope AJ & Quinn GP (2009)
Victorian Waterway Management Strategy.	Department of Environment and Primary Industries (2013)
Victoria's System of Marine National Parks and Marine Sanctuaries – Management Strategy 2003-2010	Parks Victoria (2003)
Wilson's Promontory Marine National Park Management Plan 2002. Parks Victoria, Melbourne	Parks Victoria (2006b)
Wilson's Promontory National Park Management Plan 2002	Parks Victoria (2002)
Yambuk Lake Estuary and Wetlands Management Plan	Glenelg Hopkins Management Authority (2004)

APPENDIX C: RELEVANT HYDROLOGY, BIOLOGY AND ECOLOGY

C1: Overview

A salt-wedge is formed when an intrusion of sea water along the bed of an estuary becomes thinner with distance upstream. The physical separation of marine and riverine derived water within an estuary, with the denser salty marine water sitting beneath the riverine water forms the 'wedge'. Regular cyclic variations, such as semidiurnal tides and spring tides, coupled with daily, seasonal and annual climatic variations in temperature and rainfall (and therefore freshwater flow), create a dynamic vertical and longitudinal salinity stratification. These various factors combine to influence processes such as water mixing, erosion and the transport and deposition of sediments, and other particles, including organisms (Sherwood 1983, 1985; Newton 1994, 1996). In general, dynamic patterns of flow that are maintained within the natural range of variation will promote the integrity and sustainability of aquatic ecosystems (ESA 2003).

C2: Hydrology

Typical annual hydrological cycle of an open-coast salt-wedge estuary

Several studies have demonstrated a 'typical' pattern of flow, or annual hydrological cycle, for the salt-wedge estuaries within the ecological community (e.g. Hopkins, Glenelg, and Gellibrand) (Sherwood 1983, 1985; Newton 1994). There are two main periods within a typical annual hydrological cycle (Sherwood 1983, 1985; Newton 1994, 1996; see Figure C1):

1) **Low-flow period –** characterised by salt-wedge 'emplacement', 'presence' and subsequent stagnation. This period generally occurs over late-spring to early-winter, and is characterised by minimum discharge and maximum water temperatures. Early in this period is the transitional phase of salt-wedge emplacement. Tidal intrusion results in a gradual increase in salinity along the estuary, leading to the formation of a new salt-wedge and increasingly stronger stratification and halocline formation (Figure C2). The sharpness of the halocline boundary indicates there is little exchange between the fresh and saltwater layers (Barton & Sherwood 2004; Sherwood et al. 2008). These new saline waters are well oxygenated. During the later low-flow period, mouth constriction or closure can occur, leading to reduced exchange with adjacent marine waters. Restriction of the mouth results from the gradual deposition of sands from coastal wave energy which is exacerbated if a sill is present.

   Highest salinities and temperatures generally occur in late-summer and autumn. At this time, the salt-wedge is relatively stable and may gradually stagnate, resulting in deoxygenation of deeper waters and potential build-up of hydrogen sulphide and ammonia in the deepest waters. This may stimulate a phosphate 'buffering' mechanism, causing phosphate to be released from the anoxic reduced sediments, and bacterial respiration (Newton 1994; Barton & Sherwood 2004; Sherwood et al. 2008). In addition, thermal stratification is often pronounced, with the salt-wedge cooler than surface waters in late-spring/summer as opposed to warmer during autumn/winter.

2) **High-flow period –** usually characterised by maximum discharge, retreat of the salt-wedge, and often complete flushing of all saline waters from the estuary (Figure 2). Each salt-wedge estuary has a critical level of discharge (i.e. minimum flow needed to 'flush' the estuary) which results in flushing of all saline waters from the system within one to a few days. For example, that known for the Gellibrand is 600 ML/day, Hopkins is 4000 ML/day and Glenelg is 6000 ML/day (Sherwood 1983, 1985; Barton & Sherwood 2004). This high-flow period has minimum salinities and temperatures and usually occurs in late winter to early spring.

During floods, river flow may be quite turbulent with high velocities, resulting in vigorous vertical mixing. This turbulence combined with a short residence time of flood waters, can lead to uniformity of parameters such as salinity and dissolved oxygen throughout the estuary. Flood waters introduce high levels of particulate matter into the estuary and increase turbidity. Flood waters also introduce considerable concentrations of nutrients adsorbed to particulates.

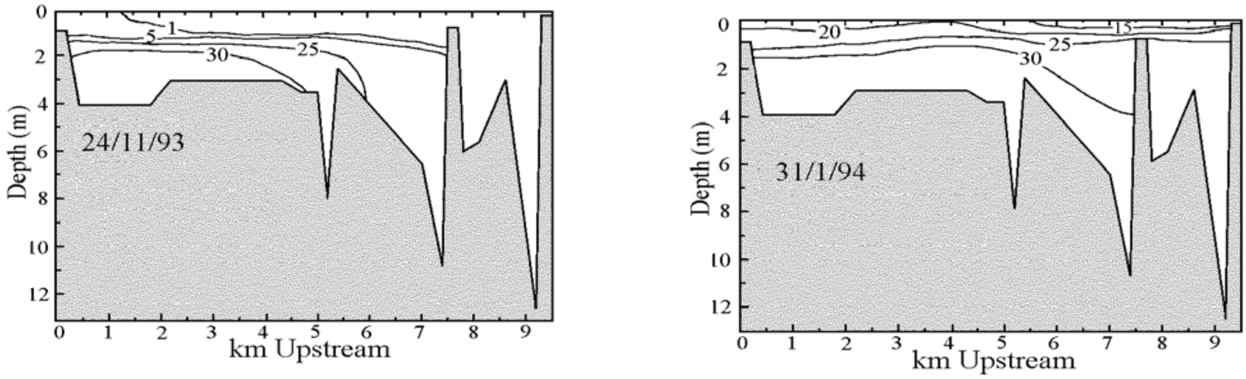

Figure C1: *Longitudinal profile of the Hopkins River estuary showing: On Left - progression of a new salt-wedge after winter flushing, and sharpness of the halocline boundary layer. [Note: The 1, 5, 25 and 30 ppt salinity isotherms are shown]; and on Right - summer salt-wedge presence. [Note: The 15, 25, 25 and 30 ppt salinity isotherms are shown](Newton 1994).*

Intermittent mouth condition

Intermittent opening and closing of the mouth is a defining feature of the salt-wedge estuaries within the ecological community (Mondon et al. 2003). The natural process of mouth closure can influence water quality and other aspects of estuary function, and may lead to the following (Mondon et al. 2003; Barton & Sherwood 2004; Pope et al. 2015):

- Cessation of tidal exchanges with the ocean, resulting in prolonged periods of conditions which favour salinity and temperature stratification, and eventually may lead to oxygen and nutrient depletion in deep waters.
- Cessation of migration of organisms (e.g. fish larvae) between river/estuary and sea.
- Increases in water level, from river flows, which may result in flooding of wetland habitats, and submergence of farm pastures, roads and infrastructure.

There is no obvious pattern to the timing of mouth closure (Barton & Sherwood 2004; Sherwood et al. 2008) but a number of factors interact to make the mouths of salt-wedge estuaries susceptible to closing (Moverley & Hirst 1999; Ranasinghe & Pattiaratchi 2003):

1) Sand deposition in the estuary mouths is generally high. These estuaries discharge into regions of high wave energy where large volumes of sand are moved along the coast by longshore and cross-shore currents, episodic storm surges and along the beach by wind. Factors such as astronomical tidal amplitude, wind speed and direction, and wave height all directly affect the amount and direction of oceanic energy that can shift sand along the coast (Haines & Thom 2007; Sherwood et al. 2008; Lloyd et al. 2009; McLean & Hinwood 2011). On Victoria's western and central coast, even small changes in sea level or wave height can cause significant changes in the location of sand deposition (Sherwood et al. 2008; McSweeney et al. 2017).

2) Estuary currents interact with longshore sediment transport and cross-shore transport which leads to the deposition of sediment across the estuary inlet entrance (Ranasinghe & Pattiaratchi 2003; Perissinotto et al. 2010).

3) Most of the estuaries are relatively shallow and may fill quickly (e.g. Eyre 1998).

4) These estuaries have a small tidal range and weak tidal currents that may not be strong enough to keep the mouth open.

In contrast to mouth closure, mouth breaching occurs when water levels overtop the berm during high river flow. Breaching is generally accompanied by scouring of estuarine sediment and an increased silt load and turbidity during the outflow phase. Importantly, breaching of the sand-barrier leads to a sudden change in water level as stored water is flushed from the system (Perissinotto et al. 2010). Such mouth discharges may be important nutrient sources for adjacent coastal waters although they can also be problematic if estuarine waters have become deoxygenated or acidic (Barton & Sherwood 2004; Arundel et al. 2008; Becker et al. 2009).

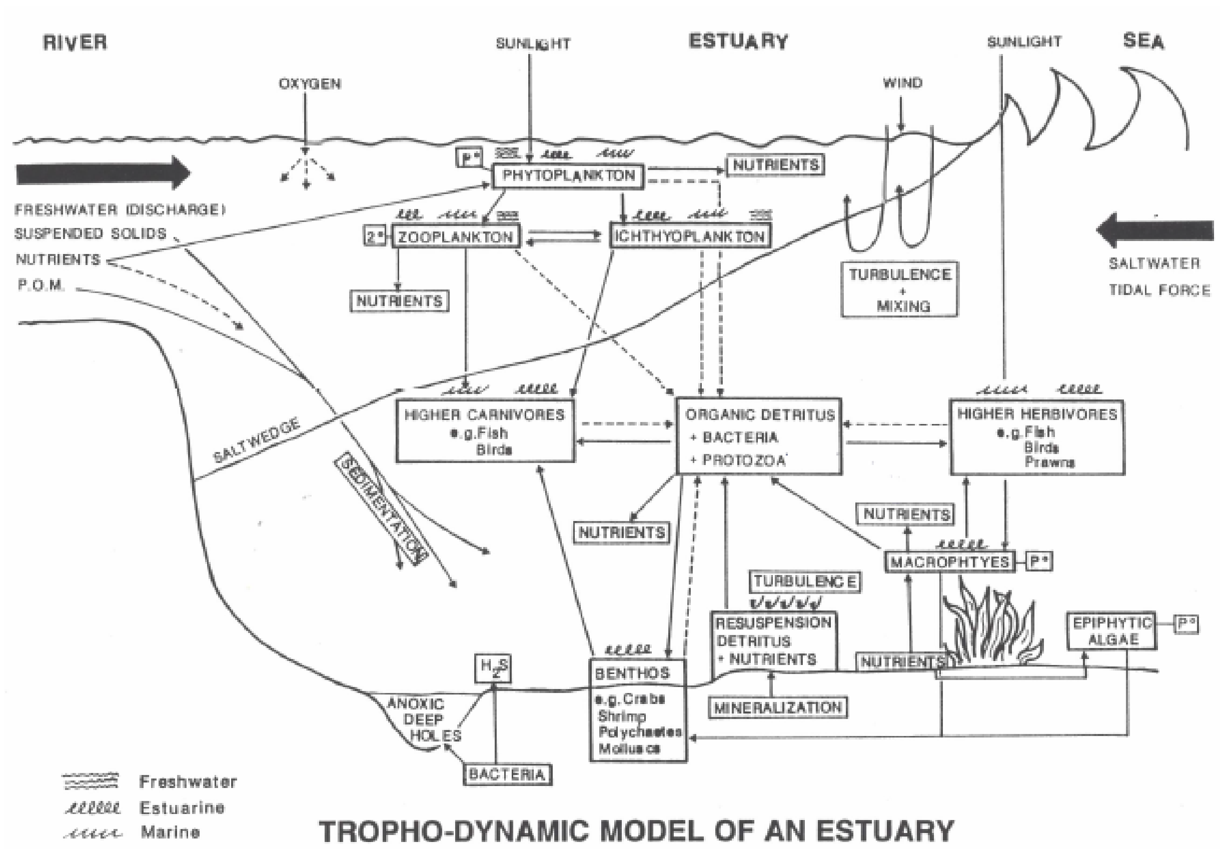

Figure C2: *Tropho-dynamic model of an estuary showing the complexity of pathways between trophic levels of organisms and the physical processes that influence the estuarine environment (Newton 1994).*

Flow and Salinity

Flow and salinity are the primary community structuring forces in estuaries (Newton 1994, 1996; Hirst 2004; Rovira et al. 2009). Factors that collectively influence the flow and salinity regime of estuaries include climate (particularly rainfall, evaporation and wind driven mixing), relative inputs of freshwater and seawater, coastal topography, currents and estuarine morphology (Deeley & Paling 1999). Freshwater flow is an important process resulting in stratification and transport of sediments and nutrients that promote retention of organisms and primary productivity in estuaries (Cloern et al. 1983). For example, density gradients (i.e. haloclines) can prevent vertical mixing by acting as a physical and biological barrier (Kurup et al. 1998).

Connectivity

Connectivity relates to the longitudinal and lateral hydrological connections between a salt-wedge estuary and its adjacent environments – the ocean, the parent river system, and the floodplain and associated wetlands. These connections support a myriad of ecological functions and interactions and the movement of biota and matter, including native fish (Zampatti et al. 2011).

The estuary channel, unlike the adjacent floodplain, is generally characterised by flowing water (currents), unstable sediments and a relatively shallow photic zone. The channel is the main conduit for transport of water, sediment, nutrients and other material, and is a corridor for dispersal and migration of biota. In the lower estuary there is potential for exchange of organisms and particulates with the adjacent coastal waters; and in the upper estuary there is potential for exchange with the riverine habitat. The littoral zone of the estuary, at the channel edge, supports a narrow band of emergent and submerged plants that forms a refuge for many animals, in particular meiofauna and macroinvertebrates, and is often a place of higher biodiversity. Floodplain wetlands occur along a water-availability gradient that governs the zones where particular plant and animal species may occur (Brock 1994).

C3: Biology, ecology and function

Community structure

Estuaries are complex ecosystems, characterised by a network of interactions and processes occurring between water flow and circulation (i.e. hydrological cycles driven by river discharge and tides), physical and chemical inputs, and biological communities as shown by the model in Figure C2.

Estuaries are home to a range of species with varying physiological tolerances, particularly to salinity. Hirst (2004) found that species diversity is often associated with changes in salinity, partly because a greater range of species is able to coexist at higher salinities. Euryhaline and estuarine fauna are generally widely distributed within estuaries and capable of tolerating a broad range of physicochemical conditions. By comparison, stenohaline species, which are marine in origin, are often restricted to a narrower band of salinities generally found closer to the entrance of estuaries.

Physical conditions such as flooding depth, salinity, groundwater moisture and scour all influence plant distribution and vary in relation to elevation, proximity to the estuarine channel and distance from the river mouth (Lloyd et al. 2008). There are normally zones that feature consistent vegetation structure and composition related to their range of tolerances to physical conditions. For example, in the Gellibrand estuary *Phragmites australis* occur extensively across the floodplain whereas *Juncus krausii* occur in a narrow band along the estuary channel (Lloyd et al. 2008).

Community structure and biomass in estuaries with intermittent mouths are determined by the interactive effects of freshwater inflow, water temperature and mouth status (Froneman 2004). Microalgae are key primary producers in intermittently open estuaries and microphytobenthic biomass is often much higher than in permanently open systems. During the closed phase, the absence of tidal currents, clearer water and greater light penetration can result in the proliferation of submerged macrophytes, such as seagrass beds. Zooplankton are primary consumers in the water-column, within the upper sediment, and as part of the meiobenthos on submerged vegetation (Newton 1994). The salt-wedge is a site of intense biological productivity that may, for example, enhance the survival of fish larvae (North & Houde 2003). The dominance of estuarine and estuarine-dependent marine fish species is an indication of the important nursery function of these intermittent systems. Marine juvenile fish recruit into salt-wedge estuaries when the mouth opens and during marine overwash events when waves from the sea wash over the sandbar at the mouth.

Phytoplankton

Phytoplankton are an important food source for zooplankton and constitute an important carbon source for local benthic and pelagic food webs in salt-wedge estuaries. They also provide an essential link between inorganic compounds and organic matter available to the higher trophic levels and top predators (Miller et al. 1996; Mortazavi et al. 2000).

Zooplankton and copepod ecology

Zooplankton have an important role in aquatic food webs and provide an important pathway for the transfer of energy (Grange et al. 2000 and papers therein). The grazing of phytoplankton by zooplankton provides a critical link between primary producers and higher trophic levels (e.g. adult and larval fish, crabs and shrimp) within the ecological community (Newton 1995; Daase et al. 2013). In addition, nutrient excretion by zooplankton contributes to the nutrient requirements of phytoplankton (Newton 1995). Meiobenthic organisms also contribute to grazing of the phytoplankton based food-chain in addition to the detrital food-chain.

The zooplankton community contains adult or larval representatives of organisms from all major habitat-types within estuaries (i.e. water column, halocline, bottom substrate, seagrass beds, and littoral vegetation). Many species of zooplankton can perform pronounced vertical migratory behaviour (usually driven by day/night or tidal cues), which means they can come into close contact with the sediments and bottom dwelling plants and animals, thus making all these components of estuaries trophically connected.

The most numerous component of estuarine zooplankton is ‘holoplankton’ which live permanently in the planktonic habitat of the water column. Important holoplankton forms are copepods, cladocerans and rotifers. Copepods consistently dominate the zooplankton fauna of coastal waters (typically 80 percent or more by numbers) (Miller 1983; Newton 1994). Australian estuaries, marine coastal forms and estuarine/marine forms of copepods are numerically and ecologically less important than true estuarine-endemic species (Bayly 1975). Most copepods are filter-feeders, although a few species also eat other copepods (e.g. the omnivore *Sulcanus conflictus*). The tiny carnivorous medusa, *Australomedusa baylii* is another important holoplankton species occurring in estuaries (Bayly 1971; Newton 1994).

The other major zooplankton component is the meroplankton which have temporary zooplanktonic life stages. These are the larval stages of animals that live in the water column or bottom substrate as adults, for example, fish, crabs, shrimps, gastropods, bivalves and polychaete worms. Many Australian fish species of commercial and recreational importance depend on estuaries during at least one stage of their life cycle (Lenanton & Potter 1987; Meynecke et al. 2006). For example, the Hopkins River estuary supports an important recreational fishery for *Acanthopagrus butcheri* (black bream) and *Macquaria colonorum* (estuary perch) (Tunbridge & Glenane 1985) and both spawn in the estuaries of the ecological community (Newton 1996).

Compared to marine and freshwater systems, salt-wedge estuaries characteristically have a higher abundance of zooplankton but lower species diversity (Newton 1994). Across the ecological community, three estuarine-endemic calanoid copepods are likely to dominate (Newton 1994); *Gippslandia estuarina*, *Gladioferens pectinatus* and *Sulcanus conflictus*. The occurrence of *Gippslandia estuarina* in the Hopkins River estuary represents the most westerly extent of its known distribution (Newton & Mitchell 1999).

In addition to their role in ecological processes, individual species of zooplankton generally have optimal ranges of salinity, temperature and dissolved oxygen for survival, although some have broader tolerances than others. With respect to copepods, water temperature and salinity are critical parameters that directly impact copepod size, reproduction, respiration, osmoregulation and metabolism, and thus their energy expenditure and estuarine positioning (e.g. Bayly 1965; Brand & Bayly 1971). The common estuarine copepod *Gladioferens pectinatus* has been recorded from the full range of salinities from freshwater to marine, and is able to regulate both hypo and hyper-osmotically, with an isosmotic point at salinity 18 (Brand & Bayly 1971). This species was also found to occur in the lowest water temperature of all the estuarine calanoid copepod species in the Hopkins River estuary (Newton 1994). Temperature can also influence the range of salinity tolerated by this and other copepod species (Bayly 1965; Jarvis 1979; Newton 1994).

Population maintenance and dormancy

Zooplankton in estuaries are continually at risk of being washed out to sea where estuarine-endemic forms cannot survive. Estuaries with a low flushing rate, such as salt-wedge estuaries, might be expected to have an essentially endemic estuarine fauna, while those with a high flushing rate (strong tidal energy) may reflect the adjacent marine zooplankton community (Newton 1994; Newton & Mitchell 1999). Similarly, estuaries in flood from high river discharge might be expected to support a mainly freshwater fauna. To maintain their populations in estuaries, many species of zooplankton have developed adaptive strategies, including migratory behaviour with the tides to maintain preferred horizontal and vertical positions, and the development of dormant life-history stages (Newton 1994; Newton & Mitchell 1999).

The specific water flow and flushing regimes of salt-wedge estuaries also have important implications for the transport, dispersal and recruitment of planktonic larvae to both estuarine and coastal marine adult populations, some of which may have commercial and recreational importance.

In the Hopkins River estuary, the use of boundary layers of least-net-flow, associated with the halocline, the bottom substrate and littoral vegetation and migratory behaviour, are prominent strategies used by zooplankton for position maintenance (Newton 1994).

A dormant life history stage is often critical to the existence of a species, ensuring its persistence during periods that are unfavourable for development, reproduction or adult survival (Newton & Mitchell 1999). Dormancy represents a spectrum of suppressed development ranging from diapause (arrested development) to quiescence (retarded development). Diapause stages cannot develop, even under optimal conditions, until the passage of a required dormancy period (Marcus 1996). In contrast, quiescence is induced by adverse environmental conditions and requires no prior acclimation, and development resumes immediately suitable conditions return (Grice & Marcus 1981). Of the three dominant estuarine copepods occurring within the ecological community, *Sulcanus conflictus* has diapause dormant eggs, *Gippslandia estuarina* has quiescent dormant eggs and *Gladioferens pectinatus* does not produce dormant eggs but rather the nauplii larvae hatch directly from an external eggs sac carried by the female (Newton 1994; Newton & Mitchell 1999). Dormancy is also utilized by the micro-jellyfish, *Australomedusa baylii*, a common zooplanktonivourous carnivore in these salt-wedge estuaries (Bayly 1971; Williams 1980; Newton 1994).

Salt-wedge dependent fish spawning and larval fish survival

Many commercially and recreationally important native fish species use estuarine habitats as nurseries or breeding grounds and have life-cycles correlated to rainfall, salinity stratification and temperature patterns (Lenanton & Potter 1987; Meynecke et al. 2006). The fish larvae assemblage of the ecological community is likely to be dominated by estuarine taxa that include demersal (e.g. goby, gudgeon) and pelagic (e.g. black bream, estuary perch) species, in addition to semi-anadromous and catadromous species (Newton 1996; Becker 2007, and see Table A3).

Many estuarine fish species have evolved spawning strategies that are adapted to the average hydrological and biological conditions of the estuary to enhance survival of their larvae (Newton 1996). Peak spawning for some fish species is in synchrony with seasonal increases in abundance of their dominant copepod prey (Cushing 1975; Sherman et al. 1984; Townsend 1984). Conversely, other species have developed a ubiquitous spawning strategy, producing larvae over a protracted period, thus allowing these populations to increase rapidly in response to favourable conditions and prey that are temporarily restricted (Sherman et al. 1984). Both strategies were found to occur in the Hopkins estuary (Newton 1996; Figure C3).

For example, black bream, a recreationally important species, completes its entire life-cycle within an estuary and is considered a keystone species and apex predator of the ecological community (Williams et al. 2013). The formation of a salt-wedge is an important process supporting black bream spawning and successful recruitment (Newton 1996; Jenkins et al. 2010; Williams et al. 2012, 2013). Physical conditions associated with salt-wedge formation may also be responsible for triggering spawning in black bream (Newton 1996; Nicholson et al. 2008). The timing and location of spawning activity is crucial to maximise the spatial and temporal overlap of larvae and prey. Having a well-defined spatial overlap between eggs and prey is an important life history strategy that maximises the reproductive success of black bream (Newton 1996; Willis et al. 1999; Williams et al. 2013). Convergence of black bream eggs at the halocline means that hatching larvae are placed within an area of increased prey availability, which in turn supports higher survival of larvae (Newton 1994, 1996; Williams et al. 2013).

The halocline is a region of increased productivity, with high densities of young copepod stages (including nauplii and copepodids), which are an important prey item for feeding black bream larvae (Willis et al. 1999; Jenkins et al. 1999). It is likely that increased nutrients and phytoplankton accumulating in the halocline assist in supporting copepod production (Jassby et al. 1995; Kimmerer 2002; Williams et al. 2013).

In addition to black bream, other fish species, such as estuary perch and *Engraulis australis* (southern anchovy), have been found to show a similar dependence on salt-wedge dynamics and halocline formation for spawning and larval feeding (Newton 1996).

Seagrass as estuarine ecosystem engineers

Ecosystem engineers are keystone species that modify and modulate the physical environment, and thus create, maintain and change habitats and resources (Jones et al., 1994; Wright & Jones, 2006). Removal or changes in local populations of ecosystem engineers can have significant impacts on the functioning of ecosystem processes, and overall long-term stability and resilience of the ecological community.

Seagrass species, such as *Zostera muelleri*, and the submerged aquatic herb *Ruppia megacarpa* (*Ruppia* is seagrass-like in appearance and function), are significant ecosystem engineers contributing to ecological and biogeochemical processes, and the integrity of the ecological community. They can form large single or mixed species stands in soft sediments (mud and sand) along the margins and mudflats of estuaries, depending on their rhizomes (or underground stems) for anchorage (Kirkman 1997; Ierodiaconou & Laurenson 2002). Seagrass beds of even small spatial extent typically support much higher biodiversity than the surrounding sediment (Hirst & Attrill 2008).

Seagrass beds perform a ‘nursery’ and ‘refuge’ function for fish, macroinvertebrates and other fauna, protecting them from predation, desiccation and currents, including avoiding being flushed from an estuary during high velocity flows or floods (Newton 1994; Powell & Matsumoto 1994; Paul & Amos, 2011; Ford et al. 2010; Sheaves et al. 2014). Seagrasses are also an important food source in estuaries and contribute greatly to estuarine productivity. The epiphytes and epifauna associated with seagrass leaves provide an important food resource for invertebrates and fish, and dead leaf and epiphyte matter provides a large organic source that fuels the detrital food-chain (Barnes & Hughes, 1982; Kirkman 1997; Ierodiaconou & Laurenson 2002; Macreadie et al. 2014). In addition to supporting biodiversity, seagrasses stabilise sediments, contribute to nutrient recycling, improve water quality by filtering out suspended sediments, and sequester carbon (Kirkman 1997; Fourqurean et al. 2012; Macreadie et al. 2013, 2014).

Summary model

The model at Figure C3 demonstrates the interconnectedness and interdependence of the physico-chemical and biological components for a generic estuarine system of the ecological community (in this case based on the Hopkins River estuary). It also supports the inference that the physical regime of these estuarine systems may be a useful ‘surrogate’ for the functional integrity of the ecological community.

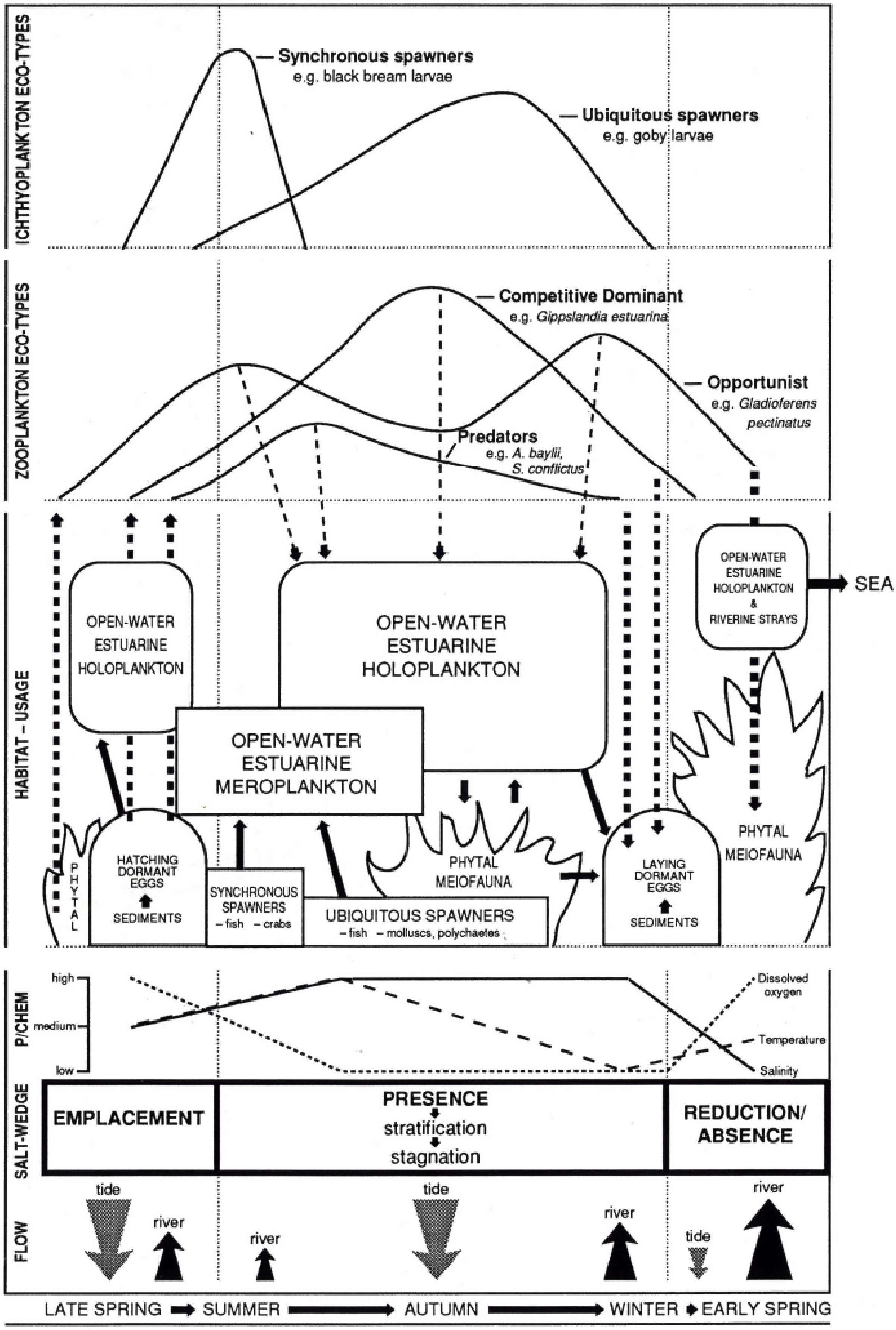

Figure C3: *Model of zooplankton ecology and habitat usage in relation to estuarine hydrodynamics and three phases of salt-wedge dynamics. Based on results of study of the Hopkins River estuary (Newton 1994).*

APPENDIX D – DESCRIPTION OF THREATS

This appendix provides information about the known and potential threats to the ecological community as well as an examination of their extent and implications.

D1: Climate change and related impacts

Climate modelling and projections by CSIRO (2015) indicate that the region of the ecological community will continue to experience a decrease in cool season rainfall, an increase in air and sea surface temperature, mean sea level rise, frequency of extreme weather events and ocean acidification, and a harsher fire weather climate. It is likely that salt-wedge estuaries are extremely vulnerable to climate change, given their reliance on salinity stratification from marine and freshwater inputs, and the associated risk of becoming marinised (Sherwood 1988; Hirst 2004). Due to other threatening processes, many estuaries within the ecological community are considered stressed systems and are less likely to be resilient to the added impacts of climate change (Mondon et al. 2003; Barton et al. 2008; Pope et al. 2015; EPA 2011). The likely impacts of climate change on the ecological community are outlined in Table D1.

Table D1: Likely impacts of climate change on the ecological community (modified from Newton 2007, OzCoasts 2008, Sherwood 1988, Voice et al. 2006, EPA 2011, CSIRO & BoM 2015, Glamore et al. 2016 and DPI 2016).

Climate Driver	Potential Impacts
Increased temperature	• Increased evaporation rates of shallow water bodies. • Decreased dissolved oxygen, with increased risk of hypoxia and fish kills. • Increased release of nutrients/toxicants from sediments into water column. • Altered rate of photosynthesis; productivity of estuary may be compromised. • Water temperature may exceed thermal tolerance of some species, which may lead to shift or decline in abundance and distribution of sensitive species. • Altered phenology, including reproduction, growth, metabolism, respiration, spawning, migration, dormancy, dispersal and community structure. • Loss of synchrony between fauna and food sources. For example as temperature increases cues that fish respond to for spawning may not correspond with abundance of invertebrate hatching. • Changes to thermal stratification of water column may affect species distribution and movements. Increased stratification may result in lower abundance of zooplankton and increased incidence of jellyfish blooms. • Increased risk of invasive species, including algal blooms, pathogens and parasites.
Sea level rise	• Increased penetration of damaging waves to estuaries and low lying coastal ecosystems, causing erosion of wetland banks, protective dune barriers and sandbars at mouths, allowing greater marine influence. Existing wetlands may become lagoonal and new wetlands may develop in low lying areas. • Landward displacement of estuarine boundaries and riparian habitat, with increased saltwater intrusion upstream and altered estuarine tidal range. In some areas it may not be possible for the estuary to adjust range or position due to artificial barriers and changes in land use. • Altered periods of mouth closure; intermittently open estuaries may convert to more permanently open estuaries. • Nursery function of estuary (i.e. for fish, crustaceans) may be compromised.
Reduced rainfall	• Lower average runoff to rivers and estuaries resulting in reduced base inflows, and altered frequency and reduced magnitude of outflows. • Altered entrance opening regimes with reduced erosion of sandbars at mouth.

	• Shallower freshwater layer in salt-wedge. • Increased marine component of estuaries, with marine zone moving further up into estuaries, when entrance is open to the sea. • Reduced flushing of estuaries resulting in increased retainment of poor quality water and increased risk of hypersalinity and anoxia and possible fish kills. • Reduced sediment inflows resulting in progressive erosion, saltwater inundation and reduced salinity stratification. • Reduced area of habitat for aquatic organisms. • Productivity and nursery function of estuary may be compromised. • Changes to dispersion and mixing of particulates, including pollution. • Altered phenology and species composition. • Loss of synchrony of species migration with entrance opening.
Extreme weather events	• Increased frequency of storm events, higher reach from storm surge and flash flooding may alter salinity distribution, affecting salt-wedge stability or lead to abrupt decreases in salinity. • Increased periods of freshwater inflows may affect sensitive estuarine species. • Extreme rainfall may result in increased runoff and sediment inflows to estuaries resulting in progressive infilling, enhanced estuary maturation, increased pollution, reduced water quality and eutrophication. • Stronger flushing influence of 'high flow' periods may result in increased loss of local communities and erosion, particularly at mouth. • Strong winds or cyclones may affect mixing, erosion, and wave climate.
Increased acidification	• Increased CO_2 concentration in seawater is resulting in more acidic oceans, affecting calcitic organisms, coastal food webs and productivity, with flow-on effects (physical and biological) to estuaries. • Heavy rain induced runoff from exposed acid sulphate soils may lead to acid flows into estuaries, affect plant and fish growth, and can lead to fish kills.
Increased fire and wind	• Increased frequency and/or intensity of aeolian dust and fire-born particulates can affect estuarine productivity and promote algal blooms. Similarly, more intense fires in catchments is likely to exacerbate runoff and sediment inflows. • Shifts in prevailing winds may influence surge frequency and wave climate.

D2: Land use and associated decline in water quality

Estuaries are the interface between terrestrial, freshwater and marine environments, making them vulnerable to anthropogenic pressures and consequent degradation (Hallett et al. 2016b). Victorian estuaries have high land use intensity (Barton et al. 2008) and clearing of native vegetation has significantly modified the landscape and altered hydrology (Barton et al. 2008; RMCG 2016). Most of the estuaries within the ecological community are impacted by land clearing and development within their catchments.

Impacts of land clearing and housing, tourism and industrial development on the ecological community include degradation and loss of estuarine habitat, altered ecology, loss of sensitive native species, and increased presence of invasive species (Barton et al. 2008). Construction of housing subdivisions adjacent to the river/estuary have the potential to alter the quality and quantity of inflows, as do 'sea wall' type structures, jetties, marinas, resorts and other tourism infrastructure (DELWP 2017b).

Other changes in catchment land use that have been found to threaten water quality and quantity include (DELWP 2017b; Honan 2012):

- establishment of blue gum plantations;

- fire management in catchments and adjacent to the estuary;
- rural drainage schemes - artificial drainage changes the volume and seasonality of flows; and
- construction of in-catchment (rather than in-stream) impoundments, such as additional farm dams preventing flow into the rivers.

D2.1: Eutrophication and algal blooms

Accelerated nutrient input from land use activities (e.g. agriculture) can lead to eutrophication and increased frequency and duration of algal blooms within estuarine environments (River Science 2005; DoW 2015). Such events are known to cause altered levels of dissolved oxygen, shading of seagrasses, toxicity and mortality of aquatic organisms (DoW 2015).

Many estuaries within the ecological community are now commonly affected by algal blooms. Algal blooms have been recorded on several occasions in the Surry River estuary as a result of elevated nutrient levels being released from sediments under anoxic conditions (GHCMA 2007). Painkalac Creek, particularly Painkalac Reservoir, is subject to seasonal blue-green algal blooms (Barwon Water 2010). Fish deaths have been recorded in the Painkalac Creek as a result of low dissolved oxygen (EPA 2007), which is likely caused by eutrophication and algal blooms. Algal blooms have also been recorded in the Curdies River (Barton & Sherwood 2004), Merri River (GHCMA 2008) and Hopkins River (GHCMA 2005).

D2.2: Pollution and contaminants

Pollution of a waterway occurs when natural and man-made contaminants enter the water either directly or indirectly (EPA 2012). Direct discharge of pollution into waterways can occur through several means, including industrial spill events (EPA 2007). Indirect sources of pollution often result from runoff from urban, industrial and agricultural areas and can include topsoil, rubbish, organic waste, metals, chemicals (e.g. herbicides) and petroleum by-products (DPI 2016).

Indirect anthropogenic sources of pollution are a major contributor of pollution to Victorian waterways and can result in significant impacts to water quality (DEPI 2013). Several recorded fish kills in Victoria have been directly attributed to waterway pollution (EPA 2007). The implications of pollution on the ecological community (Islam & Tanaka 2004), include:

- degradation of habitat and reduced water quality;
- acidification (e.g. ammonia) and chemical toxicity which can affect biota through mortality, physiological damage and deformities, reproductive failure and increased susceptibility to disease;
- eutrophication and hypoxia of waterways and associated impacts on biota; and
- biomagnification of toxins up the food chain, reduced recruitment, decline or loss of pollution sensitive species and altered species composition.

D2.3: Increased erosion, sedimentation and turbidity

Removal of native vegetation, construction of hard surfaces, overgrazing and unrestricted stock access to waterways are examples of land use that increase the rate of erosion, runoff and sediment load entering waterways (DSE 2003a; WGCMA 2015).

Increased erosion and runoff causes a higher load of suspended sediment in the water column. This results in increased turbidity, and nutrient and chemical levels, and reduced levels of dissolved oxygen and light penetration (DoW 2015; DSE 2003a). Higher than normal levels of suspended sediments in the water column causes the following issues in aquatic biota (DoW 2015; DSE 2003a):

- limited photosynthesis and reduced growth of seagrass and phytoplankton which can have effects on nutrient cycling up the food chain;
- altered behaviour and displacement of fauna;
- reduced feeding, development, growth rate and oxygen uptake; and
- increased stress, incidence of disease and mortality.

For example, the Eumeralla River catchment now contains only 2.4 percent of its estimated vegetation cover prior to European settlement. The condition of the catchment has affected the estuary area with impacts including a patchy riparian zone, bank erosion and low levels of in-stream habitat where riparian habitat has been reduced (GHCMA 2004).

Sedimentation is a natural process that occurs when suspended material settles out of the water column as water velocity decreases (Barton & Sherwood 2004; DoW 2015). However, changes in land use, in conjunction with reduced streamflow, can alter natural sedimentation rates (DoW 2015). Accelerated sedimentation has several implications on the ecological community (Barton et al. 2008; DoW 2015; DSE 2003a; GHCMA 2006b), including:

- accumulation of sediments in river channels, causing redirection of streamflow and further erosion;
- movement of 'sand slugs' down river with alteration of aquatic habitat, including infilling of river holes and deep pools, reducing habitat diversity and eliminating refuges for aquatic fauna during summer and drought;
- smothering of seagrass, filter feeding organisms and eggs (reducing gas exchange and preventing development);
- infilling of the estuary, decreasing water depth; and
- increasing nutrient and chemical load within the water column and bed material.

The upper Glenelg River has a slow moving sand slug as a result of erosion and poor historical land management (GHCMA 2006b). The slug is moving downstream at a rate of 220 m per year and the volume of sand in the river is estimated to equate to 20-30 percent of the volume of the Glenelg River estuary (Sherwood et al. 1998). The sand slug has already caused a reduction of species diversity and loss of habitat in the river and poses a substantial threat to the ecological community should it reach the estuary (GHCMA 2006b).

D2.4: Acid flows and blackwater events

Acid sulphate soils contain metal sulphides (DEDJTR 2015a) which produce sulphuric acid when exposed to oxygen (CCMA 2008; DEPI 2013). Acid sulphate soils occur naturally and, if undisturbed, are largely benign (DEDJTR 2015a; DEPI 2013). They are formed and contained in waterlogged soil, which forms a barrier to the air. Acid sulphate soils are referred to as potential acid sulphate soils (PASS) when they have the potential to oxidise (CCMA 2008). Oxygenation and production of acid occurs when acid sulphate soils are exposed to the air through disturbance (e.g. dredging) or when water is drained naturally (through drought) or artificially from the soil. This is referred to as actual acid sulphate soils (CCMA 2008). Surrounding soil can neutralise some sulphuric acid, however, sulphuric acid can move through soil, acidifying soil water, groundwater and surface water (CCMA 2008).

Actual acid sulphate soils and potential acid sulphate soils have been identified within the ecological community (CCMA 2008; DEPI 2013a). Actual and potential acid sulphate soils occur at Anglesea River, Barham River estuary and are likely to occur at Painkalac Creek. Potential acid sulphate soils occur at the Eumeralla River estuary and may occur in areas surrounding the Glenelg River, Surry River, Fitzroy River, Merri River, Curdies River, Port Campbell Creek, Sherbrook River, Gellibrand River, Johanna River, Aire River, Kennett River, Wye River, Erskine River, Spring Creek and Thompson Creek (DEDJTR 2015a).

Acid sulphate soils and acid flows have several implications for the ecological community. The lowering of the pH in the soil severely affects land and riparian vegetation cover. Sulphuric acid reduces the availability of nutrients to plants and dissolves iron and aluminium turning the soil toxic. This retards plant growth and causes most plants to die, leaving scalded and bare soil (CCMA 2008; DEPI 2013), which has additional implications of increased erosion and runoff. Heavy rainfall following prolonged drainage of acid sulphate soils results in large slugs of sulphuric acid and dissolved metals and metalloids entering waterways causing acid flows (DPI 2017a). The implications of acid flows for the ecological community (DEDJTR 2015a; DEPI 2013a; DPI 2017a) include:

- widespread mortality of aquatic biota, including fish, plants, crustaceans and microscopic organisms, due to low pH, heavy metal toxicity and depletion of dissolved oxygen;
- increased light penetration and water temperature as a result of high levels of aluminium can increase the risk of fish suffering sunburn and melanoma;
- reduced health of fish and other fauna, with acid damaged skin and gills, retarding regulation of salts and water, and increasing the susceptibility of fauna to disease. For example, affected fish are susceptible to fungal infections such as red spot disease;
- reduced growth, development, spawning and recruitment (damaged/undeveloped eggs);
- smothering of plants and streambeds with precipitated iron solids;
- habitat invasion from acid-tolerant plant and planktonic species, preventing other species from re-establishing once pH returns to normal;
- affected faunal migration due to chemical pollution acting as a barrier; and
- long term changes to habitat and species composition.

Large fish kills as a result of acid flows have been recorded in the Anglesea River (e.g. 2001) (EPA 2007; Maher 2011; Pope 2010). The Anglesea River catchment has very high levels of sulphur-containing soils with acid sulphate soils surrounding the estuary (DEDJTR 2015a; Pope 2010). The Anglesea River frequently experiences acid flows, with low pH of 3-4 and high levels of dissolved metals (Maher 2011; Pope 2010) caused by natural leaching of acid from the catchment (EPA 2007).

Blackwater events occur when high amounts of organic matter, such as leaf litter, are carried into a waterway (e.g. during high rainfall) turning the water black with carbon compounds, including tannins. Decomposition of the organic matter by bacteria results in high levels of dissolved organic carbon and chemicals (e.g. polyphenols), and low levels of dissolved oxygen (Pahor & Newton 2013). This can have catastrophic short-term consequences, including suffocation and mortality of fish, crustaceans and other fauna due to hypoxia (EPA 2007; Pahor & Newton 2013). Blackwater events have been recorded in some of the estuaries of the ecological community. For example, in 2007, an extensive fish kill was reported in the Glenelg River estuary as a result of a blackwater event occurring after heavy rainfall (EPA 2007).

D3: Modification of flow regime

D3.1: Estuary entrance modification (artificial opening)

Estuary management includes the periodic mechanical artificial opening of sand barriers at the estuary entrance to release water out to sea (Barton & Sherwood 2004). Artificial opening of estuaries is often undertaken to avoid flooding and associated social and economic impacts, such as damage to urban, industrial and agricultural land (Barton & Sherwood 2004). However, this poses a significant threat to the ecological community as it alters natural estuarine hydrodynamic cycles, natural patterns of variation in water quality, and biotic distribution and abundance (GHCMA 2006a, b).

When an estuary entrance is opened artificially, the top freshwater layer is lost. This leaves behind an anoxic or poorly oxygenated saline layer and causes a rapid increase in salinity (Barton & Sherwood 2004; GHCMA 2006b). Artificial opening of the estuary entrance can have several implications for the biological function of the ecological community (Barton & Sherwood 2004; GHCMA 2006b), including:

- extensive mortality of estuarine organisms (e.g. fish kills) if all adequately oxygenated water is lost from the estuary;
- disruption to faunal migration and reproduction cycle; and
- disruption of fish spawning cues and flushing of fish eggs and larvae.

The Surry River, Gellibrand River and Aire River estuaries have all recorded highly visible fish kills as a result of artificial opening, with unconfirmed reports suggesting the same situation has occurred in Yambuk Lake (Eumeralla River estuary) (Barton & Sherwood 2004; EPA 2007; GHCMA 2007; RMCG 2016). For example, a major fish kill occurred in the Surry River estuary in 2005 following illegal opening of the estuary mouth, which resulted in the mortality of an estimated 30 000 fish of various species (GHCMA 2007).

Artificial opening is undertaken in the estuaries of the Glenelg River, Fitzroy River, Merri River, Hopkins River, Curdies River, Barham River, Painkalac Creek, Anglesea River, Spring Creek, Thompson Creek, Gellibrand River, Erskine River and Powlett River (CCMA 2017a; GHCMA 2005, 2006a, b, 2008, 2016; Water Technology 2008; WGCMA 2015, 2017).

D3.2: Water extraction

The extraction of water resources for domestic, agricultural and industrial use in Victoria has had a widespread and long-term impact on the aquatic ecosystems of the State’s rivers, streams and estuaries (DSE 2003b). The cumulative impact of water extraction constitutes a direct threat to most estuaries within the ecological community.

Surface water is extracted from river systems through the construction of in-stream water storages (i.e. reservoirs), diversions and through direct pumping. Reservoirs are the largest single source of water extraction in most affected estuaries and they significantly modify the flow regime of river systems (DSE 2003b). Reservoirs trap a high proportion of natural inflows, substantially reduce overall downstream flows to estuaries, alter the natural frequency and seasonality of flows and floods, and extend low-flow periods (DSE 2003b). Diversions and direct pumping also contribute to the reduction of downstream flows.

The most notable impact to the ecological community as a result of altered flow regimes is longer periods of mouth closure (Barton et al. 2008). This limits flushing of estuaries and increases water residence time. Reduced flows can result in the build-up of anoxic waters; hypersalinity; increased occurrence of algal blooms; reduced channel scouring; reduced distribution of organic matter downstream; and high concentrations of ammonia and sulphide (Barton et al. 2008; GHCMA 2006a; DPI 2016; NSW Scientific Committee 2002).

Altered hydrology of an estuarine system as a result of reduced freshwater flow is likely to have several serious impacts on the ecological community (GHCMA 2006a; NSW Scientific Committee 2002), including:

- a reduction in available habitat for aquatic flora and fauna due to lower water levels;
- a reduction in lateral connectivity and reduced maintenance of ecological processes in water bodies adjacent to estuaries;
- affected spawning cues and conditions for hatching success for fish which rely on an estuary's natural hydrologic regime and adequate freshwater inflow; and
- altered faunal composition.

Within the ecological community, extraction for domestic water is undertaken in the Glenelg River, Gellibrand River (Wannon Water 2012), Barham River, St George River and Painkalac Creek (Barwon Water 2010). To a lesser extent, non-potable water is extracted from Kennett River and Wye River for domestic purposes (Planisphere 2008). Powlett River is indirectly affected by extraction for domestic water, with a reservoir located on its tributary, Lance Creek (South Gippsland Water 2011).

The Glenelg River is an example of an estuary that is strongly impacted by water extraction. The Rocklands Reservoir diverts water from the Glenelg River's upper catchment, with additional diversions in place lower down in the catchment (Barton & Sherwood 2004). Landholders and commercial licence holders extract water from the Glenelg River for irrigation, domestic, stock, industry and dairy (Southern Rural Water 2013). Black bream, for example, rely on the estuarine hydrologic regimes and adequate freshwater inflow. Missing year classes in the black bream population in the Glenelg River estuary indicates that spawning is not always successful in the estuary, likely due to changes in hydrology, flow regimes and reduced water quantity (GHCMA 2006b).

Regulation of water extraction

In Victoria, water extraction is regulated under the *Water Act 1989* and includes bulk entitlements and water licences. The water corporations that hold bulk entitlements for the use and delivery of water from reservoirs upstream of estuaries in the ecological community are Barwon Water, which owns and operates Olangolah, West Gellibrand, Painkalac and Allen Reservoirs, and Grampians Wimmera Mallee Water, which has bulk entitlements for the Glenelg River (Victorian Water Register 2017).

All water extraction for commercial purposes is required to be metred and data recorded (under the conditions of a bulk entitlement or licence). However, licenced water extraction for stock and domestic purposes is not required to be metred (Southern Rural Water 2017a). In addition, a person in Victoria does not require a licence to take water from a waterway for domestic and stock purposes if their property title includes or abuts a river or creek (Southern Rural Water 2017b). As a result, there is likely a large cumulative unquantified volume of unregulated water that is being extracted from each river system in western and central Victoria.

There is a high level of complexity relating to water extraction. There are insufficient data available to quantify the volume of surface water leaving a river system through extraction. The available data for commercial water extraction demonstrates that a significant volume of water is being taken out of any given river system annually. However, this does not represent the actual extractive volume. Other confounding factors, such as climate, evaporation and groundwater infiltration, contribute to the loss of surface water and further complicate any attempt to quantify the total volume of water extracted from the parent river systems and the subsequent impacts to the ecological community.

D3.3: Water regulatory infrastructure

Regulatory infrastructure, such as reservoirs, weirs and levees, are installed and operated for a variety of reasons including: water diversion and storage for urban and rural use; flood mitigation; prevention of salt-water intrusion upstream; and road crossings (DPI 2016; NSW Scientific Committee 2002). Regulatory infrastructure can significantly alter natural flow regimes, with longitudinal and lateral changes to water flow impacting all orders of streams and rivers, floodplain wetlands and flow of freshwater into estuaries (DoW 2015; NSW Scientific Committee 2002).

Several estuaries within the ecological community are directly impacted by the installation of regulatory infrastructure in their parent river systems (see Table D2). Although the impacts on these affected estuaries from water regulation are difficult to quantify, it is likely that the unique balance between hydrology and morphology, which is crucial for supporting and building resilience in the ecological community, has been substantially altered. For example, the capture and release of water from in-stream reservoirs alters the frequency, duration, magnitude, variability and seasonality of freshwater flows downstream to estuaries (DPI 2016; NSW Scientific Committee 2002). Weirs and flood levees also affect the downstream flow of water into estuaries, as well as the inundation of adjacent habitats (DEPI 2013; DoW 2015; NSW Scientific Committee 2002). In addition, regulatory infrastructure can have significant impacts on natural in-stream processes, including altered rates of erosion; transport and deposition of sediment (DPI 2016); and distribution of organic material (DEPI 2013; DoW 2015; NSW Scientific Committee 2002).

The physical impacts of regulatory infrastructure on waterways has several implications on the biological function of the ecological community (DEPI 2013; DPI 2016; NSW Scientific Committee 2002), including:

- impaired fish movement and migration due to the physical barriers, resulting in reduced genetic flow between populations located on either side of barriers (i.e. weirs, culverts and road crossings);
- impaired growth of biota and disruption to natural environmental cues for spawning and reproduction from altered flows; and

- loss and degradation of habitat and altered diversity and structure of faunal community.

The construction of non-regulatory infrastructure within waterways, such as road crossings and bridges, can also result in alteration of natural flow regimes (NSW Scientific Committee 2002). Road culverts and bridge pylons can modify channel morphology, increase water velocity, obstruct movement of woody debris, influence channel anabranching, provide habitat for novel (including invasive) species and alter erosion and sedimentation patterns (Suvendu 2013).

Rural drainage on the Eumeralla River has been responsible for the loss of many wetlands (Honan 2012) and similarly the eastern mouth of the Merri River is now a constructed channel. Other natural mouth openings on the Merri River historically occurred further west at Rutledge's Cutting and the Levy's area (DELWP 2017b).

The regulatory and non-regulatory infrastructure located in each salt-wedge estuary of the ecological community is listed in Table D2.

Table D2: Significant regulatory infrastructure and non-regulatory infrastructure within the rivers of the ecological community.

Estuary	**Infrastructure**
Glenelg River	Rocklands Reservoir (upstream dam)
Surry River	Princess Highway bridge
Fitzroy River	Tyrendarra School Road bridge
Eumeralla River	Unnamed bridges.
Merri River (East)	Merri bridge, Bromfield Street weir, Swinton Street bridge, Stanley Street bridge, Harris Street bridge, Wellington Street bridge, Princes Highway bridge, Caramut Road bridge.
Hopkins River	Hopkins Point Road bridge
Curdies River	Great Ocean Road bridge, Boggy Creek Road bridge.
Port Campbell Creek	Great Ocean Road bridge
Sherbrook River	Great Ocean Road bridge
Gellibrand River	Old Coach Road bridge, Janson's Access bridge, Coxens Access bridge, levee banks in upper estuary, West Gellibrand Reservoir and Olangolah Reservoir (upstream dams), and Gellibrand River North and South Offtakes.
Johanna River	Private road crossing
Aire River	Great Ocean Road bridge, Sand Road bridge.
Barham River	Great Ocean Road bridge, Apollo Bay Recreation Reserve road bridge, Barham River offtake East and West Branch (diversion weirs)
Kennett River	Great Ocean Road bridge
Wye River	Great Ocean Road bridge, Wongarra Drive bridge.
St George River	Great Ocean Road bridge, Allen Reservoir (upstream dam).
Erskine River	Great Ocean Road bridge, Erskine River swing bridge, Erskine River offtake (decommissioned diversion).
Painkalac Creek	Great Ocean Road bridge, Old Coach Road bridge, Painkalac Reservoir (upstream dam)
Anglesea River	Great Ocean Road bridge, Coalmine Road bridge, Anglesea Mine (decommissioned coal mine), Anglesea Power Station (decommissioned).
Spring Creek	Great Ocean Road bridge
Thompson Creek	Blackgate Road bridge, Thompson Creek weir (upstream).
Powlett River	Mouth of Powlett Road bridge, Nyora-Wonthaggi Rail Trail bridge, Powlett River offtake (Wonthaggi offtake), Lance Creek Reservoir (upstream dam).

Darby River	Wilsons Promontory Road bridge
Tidal River	Wilsons Promontory Road bridge
Growler Creek	None

D4: Invasive species

Aquatic ecosystems are highly vulnerable to invasion by pests. Since European settlement, many non-native species have become established in Victorian waterways, and these can have a range of impacts on the ecological community (DSE 2003c; GHCMA 2006c; DPI 2016), including:

- predation of native species;
- competition for resources and exclusion of native species;
- alteration and degradation of habitat structure and characteristics;
- introduction and transfer of pathogens and parasites;
- decline and loss of native biodiversity; and
- altered faunal composition and structure.

The following invasive species may pose a threat to the ecological community at present or in the future:

- Common carp (*Cyprinus carpio*) is a highly fecund and opportunistic species that can tolerate brackish water (10-18 ppt, Koehn et al. 2000). Carp compete with native fish for resources, destroy submergent macrophytes, reduce water quality through feeding, and cause erosion and collapse of river banks (DPI 2017b; Roberts et al. 1995; Roberts & Sainty 1996; Vilizzi et al. 2014). Carp are known to occur in low numbers in the Glenelg River (GHCMA 2006b; DEDJTR 2015b) and in Thompsons Creek (DEDJTR 2015c).
- Eastern gambusia (*Gambusia holbrooki*) is a well-established and noxious species which threatens native fish through predation and competition (DPI 2017c). The species is known to harass and impact small native fish through fin-nipping (Koehn & O'Connor 1990; Bayley & Li 1992, Arthington & McKenzie 1997; Tonkin et al. 2011). Eastern gambusia can tolerate and adapt to relatively high levels of salinity (Rowe et al. 2008). The species occurs in high numbers in the Hopkins River and the Merri River (GHCMA 2005, 2008). It is also known to occur in the Barham River, St George River, (DEDJTR 2015c) and Thompson Creek (Ryan & McGuckin 2007).
- The yellowfin goby (*Acanthogobius flavimanus*) occurs in both freshwater and saltwater, and breeds in estuaries. It threatens native fish mainly through competition for resources (DPI 2017d). The yellowfin goby occurs in the Powlett River and its estuary (DEDJTR 2015e).
- The tubeworm (*Ficopomatus enigmaticus*) is a sedentary polychaete that can occur in fresh, brackish, marine and hypersaline water. The species forms extensive calcareous reef structures that can alter habitat, community structure, water flow and sedimentation rates (Dittmann et al. 2009). The tubeworm occurs downstream in the Hopkins River (GHCMA 2005).
- Willows are highly invasive plants that degrade the condition of river channels. They trap sediment in extensive root mats, raise channel bed levels, diverting water flow over the

bank and cause erosion and channel widening (DEPI 2013). Willows also crowd out native species and their leaves can reduce water quality (DEPI 2013). Some willow species, such as weeping willow, are tolerant of brackish water (DEDJTR 2015d). Willows are a significant problem in the Fitzroy River (GHCMA 2006a) and the Gellibrand River (DELWP 2016).

D5: Disease (pathogens and parasites)

Pathogens (including viruses, bacteria and fungi) and parasites are a significant threat to native species. They can cause disease and infection, alter physiology and behaviour, limit reproduction and recruitment, cause widespread mortality in affected populations and alter community structure (Scott 1988; Roennfeldt 2013). Importantly, it is recognised that viral infection in phytoplankton (primary producers) can disrupt ecosystem dynamics by impacting the flow of carbon and nutrients to higher trophic levels (Suttle 2007).

Roennfeldt (2013) found that the copepod populations of the Hopkins River, Glenelg River and Painkalac Creek estuaries are affected by an Iridovirus. The virus causes behavioural and physiological changes, with infection of the reproductive systems, secretary gland cells and connective tissues of the host. It leads to a cessation of reproduction and in many cases, morbidity (Roennfeldt 2013). The virus in epidemic proportions leads to low copepod densities which has a bottom up effect on the food chain, particularly on copepodivorous larval fishes such as black bream (Roennfeldt 2013).

Several estuaries within the ecological community have been affected by pathogens and parasites other than viruses. For example, in 2004, black bream in Yambuk Lake estuary were found to have ulcers and lesions consistent with Epizootic Ulcerative Syndrome or Red Spot Disease but testing of samples was inconclusive (GHCMA 2006b).

D6: Extractive and recreational activities

D6.1: Fishing (commercial and recreational)

Fisheries Victoria regulates commercial and recreational fishing by stocking waterways with target fishing species, managing fishing licences, enforcing fishing gear restrictions and seasonal or area closures (DEPI 2013). Fisheries Victoria enforces bag and size limits to ensure fishing activities do not reduce the breeding population of fish species below viable levels (DEPI 2013; GHCMA 2006b).

Fishing is a popular recreational activity but the cumulative effects of poor fishing practices pose potential threats to estuaries (GHCMA 2007), including:

- inappropriate disposal of non-biodegradable waste including bait bags, fishing hooks and line resulting in entanglement of fauna;
- the taking of undersized fish and overfishing; and
- disturbance to shoreline vegetation and damage to important habitat areas.

These threats may have several implications on the ecological community (Barton et al. 2008; Blaber et al. 2000), including:

- reduced abundance of some species;
- altered age structure in some species;
- decreased recruitment of some species; and

- altered ecosystem dynamics when higher trophic levels are impacted.

The level of impact from fishing on the ecological community is reduced through regulation by Fisheries Victoria, and the risk of overfishing is considered low. However, commercial and recreational fishing remains a potential threat to all estuaries within the ecological community.

D6.2: Mining and extraction activities (coal and sand)

Mining and extraction activities pose a potential threat to at least two estuaries within the ecological community; coal mining near the Anglesea River and sand extraction works in the Glenelg River.

The Glenelg Hopkins Catchment Management Authority has implemented a program of managed sand extraction in the Glenelg River to address the ongoing impacts of sand slugs and reduce the volume of sand migrating downstream (GHCMA 2006b; GHCMA 2016). Between 2004 and 2008, the Glenelg Hopkins Catchment Management Authority was involved in the removal of 180 000 m^3 of sand from the Glenelg River at 18 different sites (GHCMA 2016). Authorised extractors continue to remove sand from the river for commercial purposes (e.g. concrete manufacture) (GHCMA 2016). Sand extraction is also used as a regulated management tool upstream of the estuary to enhance river condition and prevent movement of the sand slugs into the estuary (GHCMA 2017). It is unclear whether sand extraction is likely to have impacts on the ecological community. However, the activity is likely to cause short term or localised channel disturbance, increased turbidity and the use of machinery may cause increased localised bank erosion (Padmalal & Maya 2014).

In 1963, an open cut coal mine and coal-fired power station were established at the head of Anglesea River, altering river discharge from naturally intermittent flows to consistent year round flows (GHD 2016). The mine and power station were decommissioned in 2015, but during operation they contributed to the pollution of the Anglesea River through effluent discharge (GHD 2016). The cessation of discharge from the power station would be expected to reinstate natural and variable water flow in the Anglesea River but would also decrease the water level of the river by up to one metre, exposing acid sulphate soils (GHD 2016). It is considered that the cessation of discharge from the power station is likely to increase acid flows and metal concentrations in the river (GHD 2016) unless specific management strategies are undertaken. Since March 2016, when the mine ceased discharges to the river, a short-term option of pumping water to maintain river levels over summer was undertaken (DELWP 2017a). A longer term management plan is expected to be released in late 2017 (DELWP 2017a).

D6.3: Recreation (boating)

Boating activities in Victoria are an important economic driver for many local towns. Recreational and commercial vessels operate in most waterways in western and central Victoria, including within the ecological community. The use of boats in Victorian waterways is regulated under the *Marine Safety Act 2010* by waterway managers (DEPI 2013a & 2013b).

Boating can have several implications for the ecological community. For example, the removal of boating safety hazards such as large woody debris from waterways can negatively affect native fish populations which require woody debris for habitat (2013a & 2013b). Permanent boat mooring causes mechanical disturbance to the river bed which can substantially impact on sea grass meadows (Demers et al. 2013). In addition, the waves caused by powered boats and especially water skiing, can contribute to bank erosion (DEPI 2013a & 2013b) and disturb bird populations (DELWP 2017b). Boating may also cause some physical mixing of the stratified water column.

D7 Assessment of extent of impact of primary threats

Table D3 provides a summary of threats against each of the estuaries within the ecological community and an assessment against whether these are a current or potential threat to each estuary. This table was created based on available literature (Arundel et al. 2008, 2009; Barton & Sherwood 2004; Barton et al. 2008; Barwon Water 2010; CCMA 2008, 2012, 2013, 2015, 2017a; DEDJTR 2015a, b, c, e; DELWP 2016; DEPI 2013a, b; DSE 2003a, b; EPA 2007; GHCMA 2004, 2005, 2006a, b, 2007, 2008; Maher 2011; Pope 2010; Ryan and McGuckin 2007; Water Technology 2008; WGCMA 2015).

An analysis of Table D3 indicates that climate change is currently an identified threat to all estuaries within the ecological community. Land use and associated decline in water quality is an identified threat to over 80 percent of estuaries within the ecological community; modified flow regimes is an identified threat to nearly 70 percent of estuaries; and invasive species is an identified threat to approximately half of the estuaries within the ecological community.

Figure D1 provides a diagrammatic representation of the most widespread of the threats outlined in Table D3, and an indication of the percentage of estuaries within the ecological community potentially impacted by these key threats. In order of prevalence, the key threats to the ecological community are thought to be:

1. Climate change; threatening approximately 100 percent of estuaries.
2. Land clearing and development; threatening approximately 92 percent of estuaries.
3. Eutrophication and algal blooms; threatening approximately 88 percent of estuaries.
4. Pollution and contaminants; threatening approximately 80 percent of estuaries.
5. Increased erosion, sedimentation and turbidity; threatening approximately 68 percent of estuaries.
6. Estuary entrance modifications (i.e. artificial opening of estuary mouth); threatening approximately 60 percent of estuaries.
7. Water extraction (for domestic, agricultural and industrial use); threatening approximately 56 percent of estuaries.
8. Invasive species; threatening approximately 48 percent of estuaries.

Table D3 (a): Threats identified for open-coast salt-wedge estuaries of western and central Victoria.

Threat	Glenelg	Surry	Fitzroy	Eumeralla	Merri	Hopkins	Curdies	Port Campbell	Sherbrook
Climate change									
Sea level rise & storm surge	×	×	×	×	×	×	×	×	×
Rising temperature	×	×	×	×	×	×	×	×	×
Decline & altered seasonal pattern in rainfall	×	×	×	×	×	×	×	×	×
Modified flow regime									
Water extraction - Domestic	×								
Water extraction - Agriculture / Industry	×	×	×	×	×	×	×	p	p
Estuary entrance modification	×	×	×	×	×	×	×		
Regulatory & other infrastructure (e.g. bridges)	×	p	p	p	×	p	p	p	p
Land use and declining water quality									
Land clearing & development	×	×	×	×	×	×	×	×	×
Eutrophication & algal blooms	×	×	×	×	×	×	×	×	×
Increased sedimentation, erosion & turbidity	×	×	×	×	×	×	×	p	p
Acid flows & blackwater events	×	p	p	p	p		p	p	p
Pollution & contaminants	×	×	×	×	×	×	×	×	p
Pathogens and pests									
Disease	×	p	p	×	p	×	p	p	p
Invasive species	×	×	×	p	×	×	×	p	p
Extractive and recreational activities									
Fishing (commercial & recreational)	p	p	p	p	p	p	p	p	p
Mining & extraction activities (sand & coal)	p								
Recreation (boating)	p	p	p	p	p	p	p		

× = identified threat, p = potential threat

Table D3 (b): Threats identified for open-coast salt-wedge estuaries of western and central Victoria.

Threat	Gellibrand	Johanna	Aire	Barham	Kennett	Wye	St George	Erskine	Painkalac
Climate change									
Sea level rise & storm surge	×	×	×	×	×	×	×	×	×
Rising temperature	×	×	×	×	×	×	×	×	×
Decline & altered seasonal pattern in rainfall	×	×	×	×	×	×	×	×	×
Modified flow regime									
Water extraction - Domestic	×			×	p	p	×		×
Water extraction - Agriculture / Industry	×	p	×	×	p	p	p		p
Estuary entrance modification	×		×	×					×
Regulatory & other infrastructure (e.g. bridges)	×	p	×	×	p	p	×	p	×
Land use and declining water quality									
Land clearing & development	×	×	×	×	×	×	×	×	×
Eutrophication & algal blooms	×	×	×	×	×	×	×	×	×
Increased sedimentation, erosion & turbidity	×	×	×	×	p	p	p	×	×
Acid flows & blackwater events	p	p	p	×	p	p	p	p	×
Pollution & contaminants	×	×	×	×	×	×	p	×	×
Pathogens and Pests									
Disease	p	p	p	p	p	p	p	p	×
Invasive species	×	p	×	×	p	p	×	p	p
Extractive and recreational activities									
Fishing (commercial & recreational)	p	p	p	p	p	p	p	p	p
Mining & extraction activities (sand & coal)									
Recreation (boating)	p		p				p	p	p

× = identified threat, p = potential threat

Table D3 (c): Threats identified for open-coast salt-wedge estuaries of western and central Victoria.

Threat	Anglesea	Spring	Thompson	Powlett	Darby	Tidal	Growler
Climate change							
Sea level rise & storm surge	×	×	×	×	×	×	×
Rising temperature	×	×	×	×	×	×	×
Decline & altered seasonal pattern in rainfall	×	×	×	×	×	×	×
Modified flow regime							
Water extraction - Domestic							
Water extraction - Agriculture / Industry		p	×	×			
Estuary entrance modification	×	×	×	×			
Regulatory & other infrastructure (e.g. bridges)	×	×	×	×	p	p	
Land use and declining water quality							
Land clearing & development	×	×	×	×		×	
Eutrophication & algal blooms	×	×	×	×		p	
Increased sedimentation, erosion & turbidity	×	×	×	×		p	
Acid flows & blackwater events	×	p	p	p	p	p	p
Pollution & contaminants	×	×	×	×		p	
Pathogens and Pests							
Disease	p	p	p	p	p	p	p
Invasive species	p	p	×	×	p	p	p
Extractive and recreational activities							
Fishing (commercial & recreational)	p	p	p	p	p	p	p
Mining & extraction activities (sand & coal)	×						
Recreation (boating)							

× = identified threat, p = potential threat

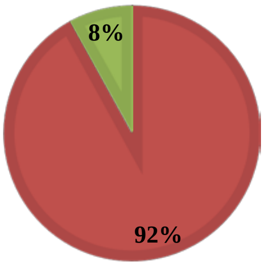

Figure D1a: Land clearing and development

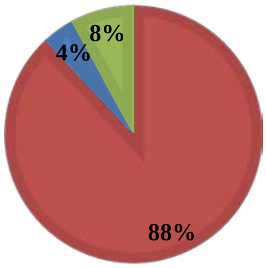

Figure D1b: Eutrophication and algal blooms

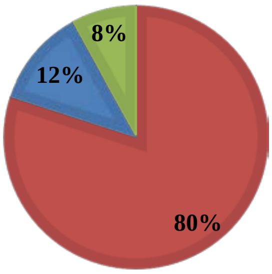

Figure D1c: Pollution and contaminants

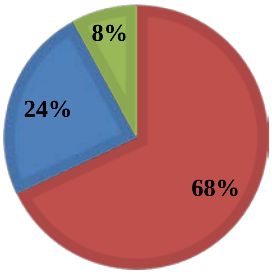

Figure D1d: Erosion, sedimentation and turbidity

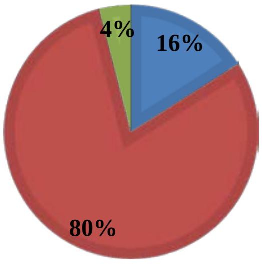

Figure D1e: Acid flows and blackwater

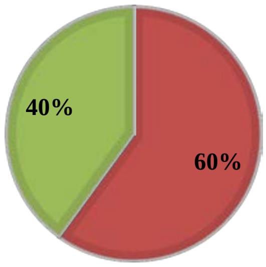

Figure D1f: Entrance modification

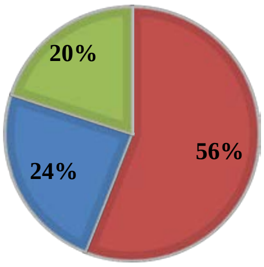

Figure D1g: Water extraction

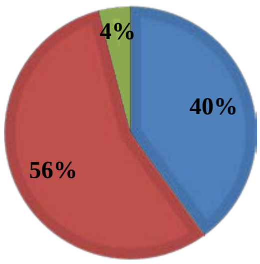

Figure D1h: Regulatory and other infrastructure

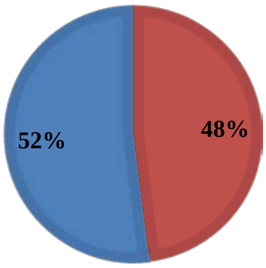

Figure D1i: Invasive species

Figure D1a-i: *Pie charts showing percentage of estuaries within the ecological community that are threatened with extinction by the identified key threats.*

Developed based on the data presented in Table D3 which is compiled from the following information sources: Arundel et al. 2008, 2009; Barton & Sherwood 2004; Barton et al. 2008; Barwon Water 2010; CCMA 2008, 2012, 2013, 2015, 2017a; DEDJTR 2015a, b, c, e; DELWP 2016; DEPI 2013a, b; DSE 2003a, b; EPA 2007; GHCMA 2004, 2005, 2006a, b, 2007, 2008; Maher 2011; Pope 2010; Ryan & McGuckin 2007; Water Technology 2008; WGCMA 2015.

APPENDIX E: DETAILED ASSESSMENT OF ELIGIBILITY FOR LISTING AGAINST THE EPBC ACT CRITERIA

This appendix presents a detailed assessment of how the ecological community meets each of the six listing criteria. It forms the Listing Advice from the Threatened Species Scientific Committee to the Minister.

E1: Criterion 1 – Decline in geographic distribution

Criterion 1 - Decline in geographic distribution			
Category	**Critically Endangered**	**Endangered**	**Vulnerable**
Decline in geographic distribution is **either**:	very severe	severe	substantial
a) Decline relative to the longer-term (beyond 50 years ago e.g. since 1750); **or**	≥ 90%	≥ 70%	≥ 50%
b) Decline relative to the shorter-term (past 50 years).	≥ 80%	≥ 50%	≥ 30%

Not Eligible for listing under Criterion 1

Evidence

Over the longer term, there has been a decline in geographic distribution (area of occupancy) of the ecological community. The estuaries of Wattle Hill Creek and the Moyne River have been permanently opened and modified to the degree that they have become marinised systems and are considered irreversibly lost to the ecological community (see Table E1). The Moyne River formerly had five rock bars which prevented incursion of salt water upstream to Belfast Lough (DELWP 2017b). When these bars were removed to open the river for navigation, marine water extended upstream. This is probably responsible for the expansion of saltmarsh and corresponding loss of Phragmites beds and Woolly Tea-tree (Swamp Scrub); also for the microerosion around the lake margins (DELWP 2017b). The Moyne therefore demonstrates what can occur if natural barriers to marine water incursion are breached (DELWP 2017b). This may have relevance to rising sea levels and coastal inundation.

Table E1: Estimated decline in geographic distribution of the ecological community (Source: A Pope 2017).

Estuary	Area of Occupancy (ha)	Timeframe	Percent Decline*
Wattle Hill Creek	18.7	> 50 years ago	0.99
Moyne River	151.3	> 50 years ago	8.03
TOTAL LOSS	**170 ha**		**9.02 %**

* Percent decline is derived using the combined total estimated surface area which is 1882.2 ha. This figure is the addition of the estimated surface area of the above estuaries (170 ha) and total estimated surface area of the ecological community (1542.2 ha) (see Table E2).

Conclusion

There has been a decline in the geographic distribution of the ecological community, but this decline is not considered to be a substantial decline (i.e. greater than 30 percent in the past 50 years). The ecological community is **not eligible** for listing under any category for this criterion.

E2: Criterion 2 – Limited geographic distribution coupled with demonstrable threat

The purpose of this criterion is to recognise that an ecological community with a limited distribution has an intrinsically higher risk of extinction, if it continues to be subjected to a threatening process. To meet this criterion, both a limited distribution and threat/s that could foreseeably cause the loss of the ecological community in a certain timeframe must be demonstrated.

Criterion 2 - Limited geographic distribution coupled with demonstrable threat			
Its geographic distribution is:	**Very restricted**	**Restricted**	**Limited**
2.1. Extent of occurrence (EOO)	< 100 km^2 = <10,000 ha	<1,000 km^2 = <100,000 ha	<10,000 km^2 = <1,000,000 ha
2.2. Area of occupancy (AOO)	< 10 km^2 = <1,000 ha	<100 km^2 = <10,000 ha	<1,000 km^2 = <100,000 ha
2.3. Patch size #	< 0.1 km^2 = <10 ha	< 1 km^2 = <100 ha	-
AND the nature of its distribution makes it likely that the action of a threatening process could cause it to be lost in:			
the Immediate future [within 10 years, or 3 generations of any long-lived or key species, whichever is the longer, up to a maximum of 60 years.]	Critically endangered	Endangered	Vulnerable
the Near future [within 20 years, or 5 generations of any long-lived or key species, whichever is the longer, up to a maximum of 100 years.]	Endangered	Endangered	Vulnerable
The Medium term future [within 50 years, or 10 generations of any long-lived or key species, whichever is the longer, up to a maximum of 100 years.]	Vulnerable	Vulnerable	Vulnerable

A number of patch size measures may be applied here, depending on what data are available.
1) The mean or the median patch area. In cases where the ecological community is highly fragmented and the patch data distribution is skewed towards mostly small patches, the median would be a more appropriate measure. Otherwise, the smaller of the mean or median should be referred to.
2) The proportion of patches that fall within each size class.
3) Changes in patch size and distribution between the modelled pre-European and currently mapped occurrences.

Eligible under Criterion 2 for listing as Endangered

Evidence

Extent of occurrence

The ecological community occurs along the western and central Victorian coast. The coastline length between the mouths of the Glenelg River (most westerly estuary) and Growler Creek (most easterly estuary) is 743 km. The extent of occurrence for the ecological community is best approximated by the area of a polygon which is bordered by the coastline between these two estuaries and a line-of-best-fit along the extent of salt-wedge penetration into the parent-rivers of the 25 systems. This area is calculated as 2268 km^2, which places the extent of occurrence under Criterion 2 as '**Limited**' (< 10,000 km^2).

Area of occupancy

The area of occupancy of the ecological community is best approximated by the estimated surface area determined by the length of maximum salt-wedge penetration for each estuary and their average width (see Table E2). The ecological community is estimated to occupy a total area of 15.4 km^2. Under Criterion 2, the geographic distribution, or area of occupancy, of the ecological community is considered to be **'Restricted'** (< 100 km^2).

Table E2: Current area of occupancy of the ecological community (Source: Pope et al. 2015).

Salt-wedge Estuary	**Area of Occupancy**	
	km²	**ha**
Glenelg River	5.520	552.0
Surry River	0.180	18.0
Fitzroy River	0.365	36.5
Eumeralla/Yambuk Estuary	1.000	100.0
Merri River (East)	0.541	54.1
Hopkins River	1.633	163.3
Curdies River	3.466	346.6
Port Campbell Creek	0.016	1.6
Sherbrook River	0.030	3.0
Gellibrand River	0.337	33.7
Johanna River	0.019	1.9
Aire River	1.030	103.0
Barham River	0.136	13.6
Kennett River	0.015	1.5
Wye River	0.005	0.5
St George River	0.025	2.5
Erskine River	0.033	3.3
Painkalac Creek	0.125	12.5
Anglesea River	0.170	17.0
Spring Creek	0.041	4.1
Thompson Creek	0.258	25.8
Powlett River	0.300	30.0
Darby River	0.024	2.4
Tidal River	0.082	8.2
Growler Creek	0.071	7.1
TOTAL	**15.422**	**1542.2**

Ongoing threats

There exist demonstrable and ongoing multiple threats to the ecological community which impact the condition and functionality of the dynamic salt-wedge nature of the estuaries and the integrity of the ecological community. A comprehensive description of these threats and their implications is at Appendix D. Most of these threats will continue to operate, intensify and compound each other. For example, climate change impacts are projected to increase and intensify. Compounding this trend are increasing population growth, land clearance and recreational use along the coastline, which will in turn impact water extraction, water quality and estuary entrance management actions. Pathogen infection (i.e. iridovirus) of the dominant copepods in several of the salt-wedge estuaries demonstrates significant threat and is potentially a symptom of the cumulative stress caused by the other threats.

Conclusion

The naturally restricted geographic distribution and specific physico-chemical regime of these dynamic salt-wedge systems, combined with demonstrable, ongoing and compounding threats make it likely that the ecological community could be lost in the ‘near’ future (e.g. the next 20 years). The Committee considers that the ecological community has met the relevant elements of Criterion 2 to make it eligible for listing as **Endangered**.

E3: Criterion 3 – Loss or decline of functionally important species

Criterion 3 - Loss or decline of functionally important species			
Category	**Critically Endangered**	**Endangered**	**Vulnerable**
For a population of a native species likely to play a major role in the community, there is a:	very severe decline	severe decline	substantial decline
3.1 Estimated decline over the last 10 years or three generations, whichever is longer of:	at least 80 %	at least 50 %	at least 20 %
to the extent that restoration of the community is not likely to be possible in:	the immediate future	the near future	the medium-term future
3.2: *restoration* of the ecological community as a whole is *unlikely* in	10 years, or 3 generations of any long-lived or key species, whichever is the longer, up to a maximum of 60 years.	20 years, or 5 generations of any long-lived or key species, whichever is the longer, up to a maximum of 100 years.	50 years, or 10 generations of any long-lived or key species, whichever is the longer, up to a maximum of 100 years.

Insufficient information to determine eligibility under Criterion 3

Evidence:

Functionally important species

This criterion refers to native species (or suites of species) that are functionally important in the processes that sustain the ecological community. For the purposes of this criterion assessment, the functionally most important species are 'keystone' species, including 'ecosystem engineers'. Keystone species maintain organisation and diversity, and contribute to the functionality of ecological communities (Mills et al. 1993; Stiling 1999). Ecosystem engineers are a type of keystone species that modify the physical environment and thus create, maintain and change habitats and resources (Jones et al. 1994; Wright & Jones 2006). Changes in local populations of keystone species, are likely to have significant impacts on ecosystem processes, trophic relationships, and the long-term stability and resilience of the ecological community.

Level of loss and restoration

It is acknowledged that there has been significant decline or loss within the ecological community (see Criterion 4) over the past 10 to 20 years, particularly in the instance of at least the Hopkins River estuary with the ecosystem engineer *Zostera muelleri* and the keystone secondary producer, the estuarine-endemic copepod *Gippslandia estuarina* (which is all but locally extinct and replaced in dominance by another estuarine-endemic calanoid copepod species with a differing biology, see Criterion 4).

Conclusion

At present, there are insufficient data to assess the level of loss or decline of *Zostera muelleri* or *Gippslandia estuarina* across the ecological community. Therefore, there is **insufficient information to determine the eligibility** of the ecological community under any category of Criterion 3.

E4: Criterion 4 – Reduction in community integrity

Criterion 4 - Reduction in community integrity			
Category	**Critically Endangered**	**Endangered**	**Vulnerable**
The reduction in its integrity across most of its geographic distribution is:	very severe	severe	substantial
as indicated by degradation of the community or its habitat, or disruption of important community processes, that is:			

Reference should also be made to the indicative restorative timeframes outlined under Criterion 3.

Eligible under Criterion 4 for listing as Vulnerable

Evidence

Criterion 4 is met if there has been a substantial reduction in an ecological community's integrity across most of its geographic distribution, as indicated by a substantial degradation of the community or its habitat; or by a substantial disruption of important ecological or physico-chemical processes, which may lead to decline in, or functional extinction of, the ecological community.

In the case of the Salt-wedge Estuaries ecological community, functional extinction would be considered to be the loss of the estuarine-endemic component of the biota, particularly the loss of estuarine-endemic copepod species, estuarine fish fauna and/or the permanent loss of a functional dynamic salt-wedge. To assess the risk of extinction under this criterion, the potential for recovery (restoration) of the ecological community must be considered as an indication of the severity of degradation or disruption.

Disruption of the natural cycle of salt-wedge dynamics

Although there may be long periods of stable salt-wedge presence, it is the dynamic nature of these estuarine systems that drives the ecology of the ecological community. The fauna and flora are adapted to a cycle of the three main phases of salt-wedge emplacement, presence and reduction/absence as outlined in Figure 2. These 'natural' salt-wedge dynamics create conditions that confer ecological and physiological benefits as outlined in Table E3.

Table E3: Ecological benefits and functions of salt-wedge dynamics.

Phase	Conditions	Benefits	Source
Salt-wedge Presence	Pronounced salinity stratification (vertical & horizontal).	• Range of estuarine salinities (moderate to high) to suit physiology and/or function of biota (e.g. optimal growth and reproduction, primary and secondary production, dormant egg hatching, fish spawning and recruitment). • Promotes nutrient cycling and phosphorus buffering mechanism of sediments. • Enhances productivity. • Promotes higher biomass of copepods and fish. • Enhances nursery function.	Newton (1994); Schlacher & Wooldridge (1996); Barton & Sherwood (2004); Jenkins et al. (2010); Williams et al. (2013); Adams (2012).
Salt-wedge Presence	Halocline formation.	• Increased area of the concentration of protists and zooplankton, therefore increased productivity and availability of prey to fish and other larvae (e.g. shrimp, crabs). • Barrier to limit mixing between layers and aids maintenance of preferred position in estuary for biota and helps to avoid export to ocean (refuge).	Newton (1994); Jassby et al. (1995); Kimmerer (2002); Barton & Sherwood (2004); Corangamite CMA (2012);

Phase	Conditions	Benefits	Source
		• Cue and location for fish spawning and enhanced larval survival. • Can flocculate particulates and help to buffer low pH (i.e. acidic flows). • Sub-halocline waters have greater seasonal temperature stability (e.g. cooler in spring/summer and warmer in autumn/winter than surface waters).	Williams et al. 2013).
Salt-wedge Reduction/ Absence (Flushing)	High discharge flows and flushing floods.	• Flushes out 'aged' stagnating or deoxygenated salt water (but deoxygenated waters generally only about 10% or less of estuary volume under 'typical' conditions) and dilutes pollutants. • Introduces high levels of particulates and nutrients (including detritus and associated micro-organisms). • Inundation of riparian and adjacent wetland zones leading to exchange of nutrients and/or biota and raises groundwater levels, wetting floodplain soils.	Arnott & McKinnon (1983); Sherwood (1985, 1988); Newton (1994); Barton & Sherwood (2004); Adams (2012).
Emplacement	new salt-wedge forming along estuary	• Fresh, oxygenated seawater introduced (a likely cue for fish spawning). • Triggers hatching of dormant eggs and life history stages (likely in conjunction with water temperature). • Enhances use of estuary as a nursery for coastal species (e.g. fish larvae).	Sherwood (1985; 1988); Newton (1994); Newton & Mitchell (1999); Barton & Sherwood (2004).

When the natural dynamics of the salt-wedge system are disrupted the integrity of the ecosystem is compromised. Table E4 provides a summary of evidence of decline in ecosystem integrity from disruption/attrition to the typical cycle of salt-wedge dynamics in the ecological community.

An assessment of the primary indicators of disruption of the integrity of the ecological community (as summarised in Table E4) relate to the key drivers of the salt-wedge hydrological cycle through declining river flow and habitat loss. These include disruption/attrition of salt-wedge dynamics through reduced freshwater inflow; more intense and frequent flash flooding; decline in natural, intermittent mouth condition; and increased artificial mouth openings.

These key drivers of change are seen to relate to declining estuarine-endemic biodiversity through declining productivity and loss of habitat. This is seen specifically through the decline/loss of keystone secondary producers and ecosystem engineers; the decline/loss of critical fish spawning cues and habitat coupled with compromised survival of fish larvae; and evidence of invasion and epidemic infection by viral pathogens.

Table E4: Decline in integrity from disruption to the typical cycle of salt-wedge dynamics in the ecological community.

Indicators of Disruption	Evidence of Change/Impact	Consequence of Change/Impact	Source
Reduced freshwater inflow (including change in quantity, quality and	• Millennium Drought (1997-2010). • Drying trend in the region since 1960; declining rainfall, run-off and river discharge.	• Loss of three phases of salt-wedge dynamics. • More frequent mouth closure. • Decline/loss of salinity stratification.	Newton & Mitchell (1999); Hall & Burns (2002); Mondon et al. (2003); Jones & Durack (2005); Barton

Indicators of Disruption	Evidence of Change/Impact	Consequence of Change/Impact	Source
timing of freshwater input)	• Reduced annual mean rainfall in the region, considered substantial compared to natural variability. • Seasonal change - less rainfall in winter/spring, i.e. estuary wet-season. • Modelling supports increased frequency and duration of extreme droughts. • Increasing trend in water extraction from population growth and urban/ agricultural development (Victoria is fastest growing State; increasing coastal pressure – 80% Victoria's population situated on coast). • Declining trend in river discharge. • More frequent mouth closures. • Reduction/loss of halocline area.	• Risk of hypersalinity and deoxygenation. • Risk of marinisation (seawater salinity only). • Loss of flushing floods – needed to 'reset' the salt-wedge hydrodynamic cycle. • Failure to flush aged, deoxygenated salt-wedge layer in winter/early-spring. • Increased residence time of water; causing increased pollutant concentration and eutrophication. • Loss of halocline habitat. • Higher salinity combined with higher temperature leads to physiological stress of biota (and potential mortality). • Changes to geomorphology. • Changes to hydrology and water quality. • Loss of estuarine-endemic fauna. • Loss of primary and secondary production. • Loss of trophic structure. • Reduced fishery resources. • Reduced habitat diversity and availability. • Lack of wedge-reformation trigger for hatching of dormant eggs of copepods, etc.	et al. (2008); Adams (2012); Gross et al. (2015); Pope et al. (2015); Sherwood et al. (2008); ABS (2016).
More intense and frequent flash flooding (but timing unclear at present)	• Disruption of stable phase of salt-wedge presence. • Disruption of salt-wedge reformation process. • Potential triggering of hatching of dormant copepod eggs at wrong time.	• Decline/loss of secondary productivity (zooplankton). • Mismatch of prey availability for larval fish and subsequent higher mortality. • Increased sediment loads and turbidity. • Decline in seagrass and macrophyte productivity.	Walsh & Mitchell (1995); Newton (1996); Newton & Mitchell (1999); Arundel (2007); Lloyd et al. (2008); Sherwood et al. (2008); Jenkins et al. (2010); Grose et al. (2015).
Decline in natural, intermittent mouth condition	• Increased frequency and duration of mouth closure (see Figure E2). • Low-flow period coincides with high evaporation rates (over 20 cm/month and exceeds rainfall), particularly	• Change in water level. • Increased evaporation rate. • Increased conditions of hypersalinity (and potential deoxygenation in wedge). • Increased water-column temperature.	Schlachert & Wooldridge (1996); Grange et al. (2000); Pierson et al. (2002); Barton & Sherwood

Indicators of Disruption	Evidence of Change/Impact	Consequence of Change/Impact	Source
	for estuaries with large ratios of surface area to depth. • Increased back-flooding of adjacent floodplain including wetlands and low-lying developments (and concomitant social pressure to resolve).	• Enhanced turbidity and eutrophication. • Increased retention of pollutants and pathogens. • Loss of connectivity to the ocean. • Impacts on migratory fish. • Reduced recruitment of marine larval fish into estuary nursery areas. • Change to composition of adjacent shallow-water flood-zone fish assemblage.	(2004); Becker (2007); Hirst (2004); Pope (2006); Sherwood et al. (2008); Whitfield et al. (2008); Perissinotto et al. (2010); van Niekerk et al. (2013); Pope et al. (2015).
Artificial mouth opening	• Increased incidence of artificial opening of estuary mouths (see Figure E2). • Increased social pressure for artificial opening of estuary mouths. • Increased 'illegal' opening of estuary mouths. • Potential draining of surface oxygenated water (i.e. DO > 5 mg/L), leaving behind older poorly oxygenated or anoxic deeper water. • Highly visible mass 'fish kills' recorded in the Surry, Gellibrand, Aire, and Yambuk estuaries.	• Higher tidal exchange and intrusion of marine species. • Potential increased width of estuary. • Impacts from rapid salinity change. • Thinner freshwater surface layer subject to greater mixing. • Loss of stratification and halocline. • Changed inundation regime of riparian zone. • Potential export/loss of fish eggs and larvae. • Reduced habitat diversity and availability. • Reduced foraging habitat for fish and birds. • Reduced breeding habitat for fish and birds. • May lead to gradual shallowing of the estuary due to sedimentation. • May cause mass 'fish kill' from deoxygenation, blackwater or acid flows. • Use of explosives causes shock waves that are harmful to fauna.	Ibanez et al. (1997); Kelly (2000); Barton & Sherwood (2004); Hirst (2004); Becker (2007); Arundel et al. (2008); Becker et al. (2009); McKenzie et al. (2011); Lill et al. (2012); Milbrandt et al. (2012); Whitfield et al. (2012); Ribeiro et al. (2013).
Decline in water quality and ecological function from increased water temperature	• See Criterion 5 (climate change impact). • Increased turbidity can lead to increased water temperature. • Decline/loss in thermal stratification. • Projected increased duration of combined temperature and salinity maxima.	• Can alter physical, chemical and biological properties in estuaries. • Affects metabolic rate and oxygen consumption of estuarine organisms. • Influences rates of photosynthesis. • Influences dissolved oxygen and other dissolved gas concentrations (e.g. warmer water less able to hold oxygen). • Increases sensitivity of estuarine organisms to pollution, parasites and disease. • Increases solubility of toxic compounds (e.g. heavy metals, ammonia).	Bayly (1965); Ough & Bayly (1989); Kennedy 1978); Hall & Burns (2001 and references therein, 2002); FEI (2014); Grose et al. (2015).

Indicators of Disruption	Evidence of Change/Impact	Consequence of Change/Impact	Source
		• Temperatures above 35°C can alter metabolic function in aquatic organisms. • Impact the rate and degree of deoxygenation of the salt-wedge. • Impact temperature of halocline and associated productivity. • Impact on development and mortality of meroplankton. • Higher temperature combined with higher salinities can lead to increased mortality of estuarine copepods (upper salinity tolerance is often temperature-dependent) and impact on egg production. • May impact 'trigger' function for hatching/'release' of dormant eggs and other life-history stages of invertebrates.	
Decline in water quality and ecological function from increased eutrophication and deoxygenation from associated algal blooms; decay of organic matter (blackwater flows); acid flows	• Longer periods of salt-wedge stagnation leading to oxygen depletion (DO < 1-2 mg O_2/L) and build-up of hydrogen sulphide. • Increased levels of nutrients and organic matter. • Increased incidence of algal blooms. • High proportion of adjacent acid sulphate soils and documented acidic flows. • Documented blackwater events.	• Periods of toxic conditions and oxygen depletion from microbial consumption, causing stress/mortality of biota. • Anoxic bottom waters can trigger release of sediment-bound nutrients and associated algal blooms. • Low DO leaves aquatic organisms in a weakened state and more susceptible to disease and pollutants. • Excessive growth of macroalgae (e.g. Cladophora), promoting hypoxia or anoxia. • Mass mortality of fish (i.e. 'fish kills')	Kelly (2000); Maher (2001); Barton & Sherwood (2004); Barton (2006); Pope (2006); Becker (2007); Becker et al. (2009); Jiménez Cisneros et al. (2014).
Decline in water quality and ecological function from increased sedimentation and turbidity	• Increasing catchment land use, clearing and development (urban and agricultural). • Erosion of estuary banks in places. • Increasing sea level & storm surge. • Higher turbidity. • Higher sedimentation rates.	• Gradual infilling of estuary. • Increased nutrient loads and organics; stimulating phytoplankton production which may increase turbidity. • Turbidity limiting light penetration, primary production and distribution of macrophytes. • Smothering of biota. • Altered availability, mobility and depth of benthic habitat. • Trapping/flocculation of sediment at halocline. • Store and modify organic matter, nutrients and pollutants.	Carter & Rybicki (1990); Barton (2006); Scheltinga & Moss (2007); Adams & Riddin (2007); Snow & Taljaard (2007); Arundel et al. (2009).
Loss of Connectivity (between:	• Increased natural and artificial mouth closure (and	• Prevents upstream penetration of saltwater.	Walsh & Mitchell (1995); Newton &

Indicators of Disruption	Evidence of Change/Impact	Consequence of Change/Impact	Source
estuary and ocean; estuary and river; estuary and adjacent riparian/ wetland areas)	see Figure E2) – from reduced discharge levels. • Dams, weirs or upstream offtakes (e.g. Glenelg, Gellibrand, St George, Painkalac, Barham, Thompson). • Presence of levees, seawalls and bank armouring. • Reduced fish diversity, /biomass, and cohorts.	• Prevention of movement/migration of fauna upstream, downstream and laterally. • Limits migration, spawning and recruitment for catadromous fish (e.g. eels, Australian grayling) and semi-anadromous fish (e.g. southern anchovy). • Reduction in diversity of habitat. • Limited coastal dispersal ability between estuaries for some species/life-history stages (e.g. *Paratya australiensis*; euryhaline fish).	Mitchell (1999); Becker (2007); Arundel et al. (2009); Becker et al. (2009); Pope et al. (2015).

Artificial Mouth Opening

Figure E2 provides records of natural versus artificial mouth openings for some estuaries in the ecological community. The estuaries of Lake Yambuk, Fitzroy, Glenelg, Hopkins and Merri had 4–14 artificial openings from mid-2006 to mid-2012 (Pope et al. 2015). One artificial opening of the Merri was noted as being conducted to relieve flooding of orange bellied parrot saltmarsh feeding area (Pope et al. 2015). Each of these systems also had ‘unknown cause’ openings (2–7) which were potentially illegal openings, or unrecorded natural openings. Overall there is a clear pattern of the number of artificial openings exceeding natural openings which indicates a severe disruption to the integrity of the ecological community.

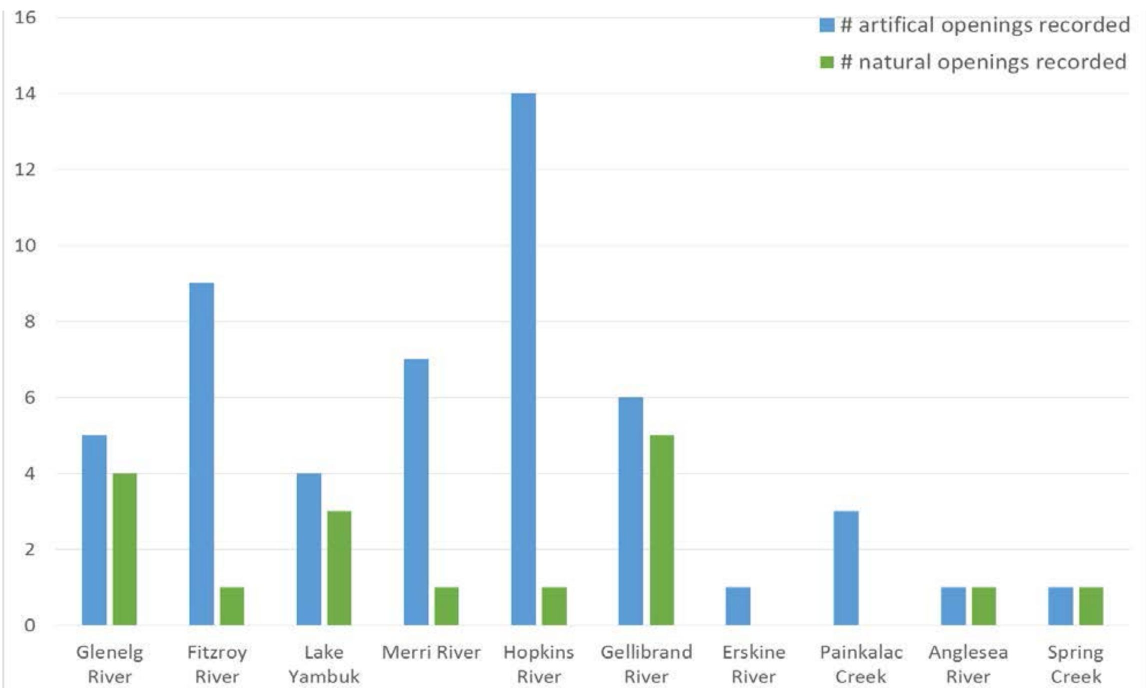

Figure E2: *Numbers of artificial and natural opening of estuaries with regularly recorded data where at least one artificial openings took place. Periods of observation varied from 18 months and 6 observations to 6 years and 661 observations. Data was sourced and compiled from a variety of sources, including from Catchment Management Authorities, Estuary Watch, researchers and water height loggers (Pope et al. 2015).*

In 2007, a formal Estuary Entrance Management Support System was released in Victoria which features a decision support tool that guides estuary managers when making the decision whether or not to artificially open an estuary (EEMSS 2007). However, the consequences of artificial opening trigger heights on estuarine ecology, particularly on wildlife or wetland habitat, have yet to be reviewed (Barton & Sherwood 2004).

Decline in water quality

Water quality within the ecological community has declined significantly due to a range of factors, (see Appendix D). Water temperature influences several other parameters and can alter the physical, chemical and biological properties of estuaries (see Figure E3). Anthropogenic activities resulting in increased input of nutrients and organic matter to the estuaries are likely to accelerate the extent of oxygen depletion due to microbial consumption. Water quality assessments undertaken by CMAs in the river basins that feed into the ecological community produced results ranging from poor to excellent, with about half of the reaches tested found to be in moderate condition. River reaches in the best condition were located away from development and cleared land (e.g. in forested areas of the Glenelg and Surry rivers) (DEPI 2013a).

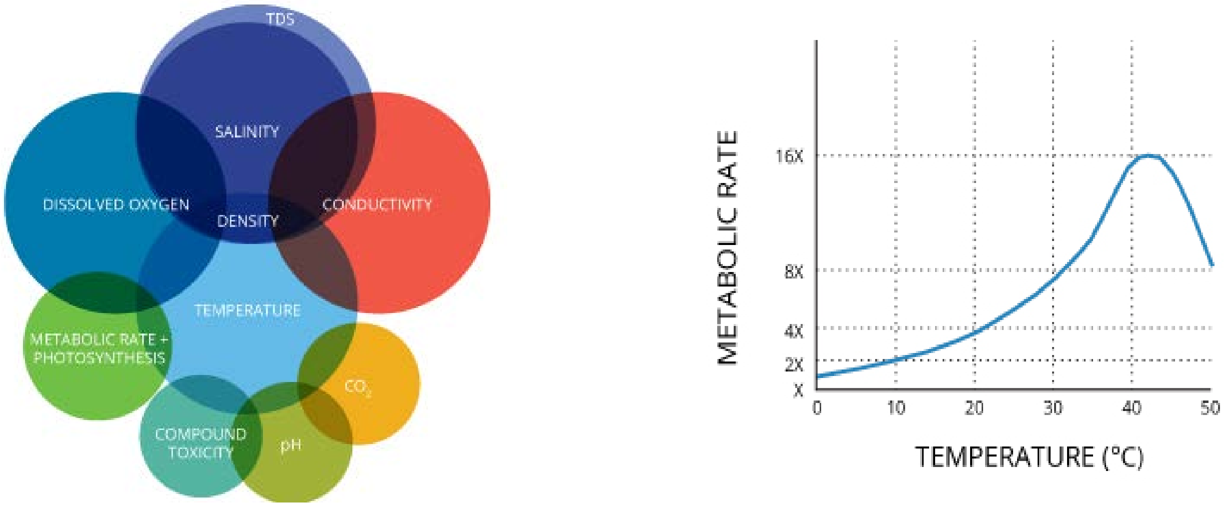

Figure E3: *On left – Temperature affects a range of other physico-chemical parameters in the water column of estuaries. On right – increasing temperature leads to increased metabolic rate and oxygen consumption of estuarine biota (Source: FEI 2014).*

It is particularly important that the aged, deoxygenated and toxic waters in the saline layers of salt-wedge estuaries are periodically flushed from the system to avoid ill effects to biota. However, the limited tidal input in wave-dominated estuaries, such as those of the ecological community, makes them more prone to hypoxic events and more reliant on riverine flows and flushes to provide fresh oxygenated water. The declining trends in rainfall, river discharge and increasing demands on water abstraction are likely to have reduced the frequency of these flushing events and increased instances of deoxygenation, algal blooms and fish kills.

Decline in connectivity

There are a range of regulatory and other infrastructures utilised across the ecological community (see Appendix D). Most of these are small bridges and roads which would have negligible impact on these estuarine systems, apart from localised changes to current flow. However, several of the estuaries have reservoirs, weirs or offtakes upstream (i.e. Glenelg, Gellibrand, St George, Painkalac, Barham and Thompson). Artificial upstream barriers prevent movement of biota, particularly fish, up and downstream, and can also reduce the diversity of estuarine habitat by preventing upstream movements of saltwater (Arundel et al. 2009). Loss of connectivity leading to a decline in integrity of the ecological community is mainly a result of reduced discharge levels, potentially leading to longer and more frequent periods of mouth closure. Several species of fish that inhabit or use the ecological community's estuaries (e.g. eels, Australian grayling and southern anchovy) depend on an open estuary entrance for migration, spawning and recruitment.

Decline/loss of keystone secondary producers

There are two hallmarks of keystone species: their presence is crucial in maintaining the organisation and diversity of their ecological communities, and these species are 'exceptional', relative to the rest of the community, in their importance (Mills et al. 1993). Dominant calanoid copepods are keystone species in estuaries (see Appendix C3). Within the ecological community, there are two important keystone zooplankton species that perform the role of secondary producing grazers, feeding on both the phytoplankton- and detrital-based food chains; *Gippslandia estuarina* and *Gladioferens pectinatus*. Table E6 provides further information on their ecological role, features and how they have been impacted.

Due to its primitive nature and limited distribution, Newton & Mitchell (1999) suggest that it is likely that *Gippslandia estuarina* is mainly represented by 'refuge populations' in favourable habitats such as that afforded by stable periods or locations in stratified estuaries.

While the opportunistic *G. pectinatus* appears to have assumed the main role as secondary producer copepod in the Hopkins estuary (and likely other nearby estuaries within the ecological community), it does not typically reach the density maxima (and thus productivity) that the specialist *G. estuarina* is capable of (Newton 1994). Newton (1996) found that the mass hatching of dormant eggs of *G. estuarina*, which coincided with post-flood salt-wedge reestablishment, provided abundant prey for the larvae of estuarine and marine fishes that had adaptively cued their reproductive cycle to take advantage of this food source (see Appendix C3).

Decline/loss of ecosystem engineers

The seagrass species, *Zostera muelleri* and *Heterozostera tasmanica*, along with the submerged aquatic herb *Ruppia megacarpa*, are significant ecosystem engineers of the ecological community (see Table E5 and Appendix C3). These important ecosystem engineer species have been completely lost in at least two of the estuaries within the ecological community, with the status of seagrasses in the other estuaries currently unknown.

In 2000, Ierodiaconou & Laurenson (2002) surveyed and mapped seagrass beds along the length of the Hopkins estuary. They found seagrass growing in a 5-15 m band along the sides of the channel throughout most of the length of the estuary, with some sections with shallow mudflats supporting more extensive coverage – the largest bed being 223 m at its widest point. They estimated that the estuary had 25% coverage by area of the three species. *Ruppia megacarpa* dominated shallow waters from 0-0.5 m depth throughout the estuary, while *Z. muelleri* dominated depths from 0.5–1.9 m throughout the estuary and occurred in mixed stands with *H. tasmanica* in downstream sections.

Seagrass was observed to be present (but abundance unknown) in the Hopkins in 2014 (Dr Paul Carnell pers. comm. October 2016). Then in 2016, extensive sampling undertaken by Deakin University staff and students (benthic grabs, coring and scuba diving) along the length of the Hopkins estuary found no evidence of seagrass; including rhizomes, leaves or seed banks (D. Ierodiaconou pers. comm. November 2016).

Similarly, *Zostera* beds were present in the Curdies estuary in 2014 but no longer present in 2016 (P. Carnell pers. comm. November 2016). The reasons for the complete disappearance of these species is unclear, but hypothesised to be caused by a combination of pressure from the Millennium Drought followed by drought-breaking floods in early 2011, combined with increasing pressure from catchment development leading to dieback (Dr D. Ierodiaconou & Dr P. Carnell pers. comm. October 2016).

Loss and fragmentation of seagrass beds via nutrient loading and turbidity are thought to be the main drivers of seagrass decline (Kirkman 1997; Short and Neckles, 1999; Kilminster et al. 2015), based on evidence from two of the estuaries. Pressures from activities such as land reclamation, coastal development and localised activities (including recreational boat mooring and bait digging) are a major cause of physical disturbance and damage to seagrass beds. Seagrass beds are generally shallow by nature and sensitive to the main drivers of climate change (Short & Neckles 1999; Bjork et al. 2008; Jones et al. 2011 in Mieszkowska et al. 2013).

Recovery and recolonisation from losses such as those in the Hopkins or Curdies estuaries are rare for temperate species of seagrass, and may take years to decades (Kirkman 1997; Jarvis et al. 2014; Thompson et al. 2014). For example, in Durras Lake, New South Wales, a community of *Zostera* decimated by hypersalinity (~50 psu) took 6 years to re-establish after salinity returned to acceptable levels (Kilminster et al. 2015). Jarvis et al. (2014 and references therein) suggest that the lack of a persistent seed bank may reduce the resilience of *Zostera* to multiple or repeated stress events. This may be a similar risk for seagrass beds within the ecological community, particularly in the Hopkins estuary, for which no viable seed bank was found in 2016. Attempts to replant seagrasses have limited success (Kirkman 1997; Orth et al. 2010; Jarvis et al. 2014**;** Macreadie et al. 2014).

Decline /loss of critical fish spawning cues/habitat and larval fish survival

Black bream, *Acanthopagrus butcheri*, is a keystone species and apex predator of the ecological community (see Table E5). Black bream require salinity stratification, halocline presence, optimal temperature and adequate prey availability to maximise larval survival (Newton 1996; Williams et al. 2013). Freshwater flow leading to formation of a salt-wedge (i.e. salinity stratification and halocline formation) has been found to be critical for spawning and larval survival of this fish species (Newton 1996; Nicholson et al. 2008; Jenkins et al. 2010; Williams et al. 2012, 2013; and see Appendix C3). Salinity structure has also been linked to recruitment variability (Jenkins et al. 2010). Jenkins et al. (2010) reported a positive (although non-linear) relationship between freshwater flow, the level of stratification and recruitment of black bream, with the greatest recruitment occurring at intermediate flows. These authors also found a link between flow and year class strength (i.e. age cohorts).

Williams et al. (2013) suggests that sufficient freshwater flow needs to be delivered to an estuary to generate the stratified conditions that correspond to increased concentration of black bream eggs, larvae and their potential prey. For example, during the Millennium Drought in Victoria, reduced stratification of the Gippsland Lakes led to significant recruitment failure and decline in the black bream population (Williams et al. 2013). These findings imply that a marked reduction in flows such as through drought, abstraction of water, or future climate change, is likely to reduce the stratified area of the estuaries within the ecological community. This in turn would restrict the area suitable for black bream; and potentially for other species that utilise the estuaries of the ecological community to spawn, or as larval nursery habitats.

Climate change is predicted to impact on spawning and larval survival of black bream and other estuarine fishes in the ecological community. Forecasts have suggested a probable reduction in freshwater river flows in the region of the ecological community of between 5 and 45 percent by 2030 (Jones & Durak 2005). Temperatures are projected to rise considerably (see Criterion 5) which may directly impact black bream which dependent on restricted temperature ranges for spawning and optimal egg and larval survival. In addition, hypoxia and anoxia are becoming increasingly common in highly stratified estuaries where there is high nutrient loading through agricultural activities or prolonged mouth closure from extended low flows (Jiménez Cisneros et al. 2014).

These combined impacts (see Table E5) demonstrate that threats to the ecological community related to reduced discharge (from climate change and increased water extraction, see Appendix D) and rising temperature are impacting spawning habitat, prey availability and recruitment, of fish species. This may not represent a severe change on its own but contributes to an overall substantial loss of integrity within the ecological community.

Decline in integrity from invasion and epidemic infection by viral pathogens

Infections from the iridovirus ZoopIIV [HR][17], were first detected in 2007 in the estuarine copepod *Gladioferens pectinatus* from the Hopkins River estuary (Roennfeldt 2013; and see Table E5). This was the first discovery of an iridovirus in estuarine copepods and one of the first in mesozooplankton globally (Roennfeldt 2013). Virus persistence and increased copepod morbidity were observed over late spring and summer in the Hopkins estuary (Roennfeldt 2013) and may be indicative of environmental stress (*sensu* Williams et al. 2005; and see Appendix D). This is even more concerning given the identified relationship of the spread of infection and morbidity of the copepods with increased temperature, and the projected climate change derived increase in temperature in the region of the ecological community.

The widespread infection of the Hopkins estuary by iridovirus and its discovery in other estuaries within the ecological community (see Table E5), combined with the projected temperature rise contributes to a substantial reduction in the integrity of a key part of the ecological community.

Conclusion

The combined impact of multiple and cumulative threats (in particular climate change, agricultural/urban development, water extraction, and pathogens; refer Appendix D and Table E5) have reduced the integrity of the ecological community through:

- Disruption and attrition of natural salt-wedge dynamics, including: loss or decline in the ‘typical’ hydrological cycle of salt-wedge flushing, emplacement and presence; loss/reduction or projected reduction in salinity stratification and the threat of marinisation; loss/ reduction or projected reduction in area of functional halocline; loss of flushing floods or flash floods occurring in a normal season.
- Decline in functional ‘intermittent’ mouth condition, including more extended periods of closure and environmentally inappropriate ‘artificial’ opening (which can result in major fish kill events).

[17] [HR] (Hopkins River Zooplankton Invertebrate Iridescent virus, Family Iridoviridae – named with assistance of the International Committee on Taxonomy of Viruses).

- Declining water quality, including: increased or projected increase in water temperature, eutrophication, algal blooms, sedimentation, turbidity, deoxygenation and pollution.
- Loss of connectivity between the estuary and the ocean (through increased mouth closure), and the estuary and the river, and associated riparian and wetland floodplains (through decreased flows at the appropriate season).
- Loss of keystone biodiversity and related function in some estuaries, including: decline/ loss of estuarine calanoid copepods as keystone secondary producer species, also resulting in loss of key prey for fish larvae; decline/loss of key ecosystem engineers (i.e. seagrass beds), also resulting in loss of productivity, nursery habitat, nutrient recycling, detrital food-chain pathway, and habitat for many species of epiflora and epifauna.
- Decline/loss of fish spawning cues and habitat, and compromised survival of estuarine fish larvae.
- Infection of keystone copepods by 'new' viral pathogens.

These reductions in integrity have impaired the resilience and function of the ecological community for much of its range due to ongoing natural and anthropogenic pressures, which will further exacerbate the continued and combined impacts of the various threats. In particular, the disruption to salt-wedge dynamics, the loss of keystone and ecosystem engineer species, and widespread pathogen infection are cause for concern regarding the re-establishment of ecological processes, species composition and community structure within the range of natural variability for the ecological community.

Many of the estuaries in the ecological community have management plans in place, and there is now a more formalised decision support scheme regarding estuary entrance management (EEMSS 2007). However, the high population growth in the region, combined with ongoing and increasing multiple threats, and the losses and declines already observed, means that the integrity of the ecological community is unlikely to be restored in the medium-term future.

The Committee considers that the change in integrity experienced by the ecological community is substantial and restoration across the extent of the ecological community is unlikely in the medium-term future. Therefore, the ecological community is eligible for listing as **Vulnerable** under this criterion.

Table E5: Decline in integrity from decline/loss of keystone biodiversity and related function in the ecological community.

Key Symptom/Indicator	Ecological role/Ecotype	Features	Impact	References
Decline/loss of Keystone species – estuarine-endemic calanoid copepods				
***Gippslandia estuarina:* estuarine-endemic calanoid copepod**	• Main secondary producer. • Niche specialist species. • Direct indicator of phase of salt-wedge dynamics (statistically significant correlation). • Primitive, monotypic species. • Limited geographic distribution and record of occurrence.	• Dominant zooplankton and copepod species in 18 month study of Hopkins estuary under reference conditions in mid 1980s. • Absent during floods; rapid population increase during salt-wedge emplacement; maxima during salt-wedge presence (autumn). • Extremely high density with mean-maxima of 300,000/m^3. • Initial population increase from hatching of dormant eggs; also an important and 'cued' food source for fish larvae. • Produces quiescent dormant eggs (only limited viability and dispersal ability). • No vertical migratory behaviour (less able to affect position in an estuary apart from using barrier of halocline and berm).	• Study of Hopkins in 2007 to 2013 found *G. estuarina* to be virtually locally extinct and replaced by *G. pectinatus* as the dominant species. • Unknown if viral pathogen contributed to demise of *G. estuarina* in the Hopkins, but the few individuals observed (<30 in four years) were all infected with iridovirus (Roennfeldt 2013).	Bayly & Arnott (1969); Newton (1994); Newton (1996); Newton & Mitchell (1999); Roennfeldt (2013)
Gladioferens pectinatus: **estuarine-endemic calanoid copepod**	• Secondary producer. • Opportunistic species. • Post-flood pioneer species. • Broad geographic distribution, with congener in Western Australia.	• Second dominant zooplankton and copepod species in 18 month study of Hopkins estuary under reference conditions in mid 1980s. • Present in low numbers in water-column during and directly after a flood. • Can both hypo- and hyper-osmoregulate and survives freshwater for extended periods (2-1 months). • Spines on back enable attachment to vegetation as refuge from flood and flows. • Population lives partly in water-column and partly among littoral vegetation. • Population peaks occur pre-flood (early winter) and post-flood (spring), i.e. periods when *G. estuarina* is in decline or establishing.	• Since the late-2000s, and possibly before, replaced *G estuarina* as the dominant species. • Since the late-2000s, and possibly before, also suffering infection, reproductive failure and morbidity from viral pathogen (iridovirus).	Brand & Bayly (1971); Kennedy (1978); Hodgson (1979); Sherwood et al. (1987); Sheehy & Greenwood (1989); Newton (1994); Newton & Mitchell (1999); Roennfeldt (2013)

Key Symptom/Indicator	Ecological role/Ecotype	Features	Impact	References
		• Density mean-maxima of 87,000/m^3 (an order of magnitude less than *G. estuarina*). • Similar succession patterns found across the range of *G. pectinatus*. • No dormant eggs. • Has vertical migratory behaviour so can affect its position in estuary.		
Decline/loss of Ecosystem Engineer species - seagrass				
Seagrass species – ***Zostera muelleri*** ***Heterozostera tasmanica*** ***Ruppia megacarpa*** (a seagrass-like submerged aquatic herb)	• Ecosystem engineers. • Significant contribution to primary production via seagrass itself and associated epiphytes. • Significant contribution to detrital food-chain. • Habitat for meiofauna (most are detritivores). • Significant contribution to nutrient recycling. • Provides habitat and protective shelter/refuge from predators and currents. • Provides 'nursery' function for larval fish.	• Dominant habitat for the estuarine shrimp *Paratya australiensis*, harpacticoid copepods (35 species), and larval fish. • In 1995, extensive seagrass beds were recorded in the Surry, Fitzroy, Hopkins, Painkalac and Anglesea. • In 2000, seagrass/*Ruppia* of Hopkins mapped and found to be 25% coverage by area. • In 2014-2016, the Surry, Fitzroy, Sherbrook and Aire were reported to have healthy seagrass beds. • In 2016, 100% loss of seagrass and *Ruppia* reported for Hopkins, including rhizomes, leaves and seed banks). • In Curdies, *Zostera* beds present in 2014 but not 2016.	• Local extinctions of seagrass and Ruppia in Hopkins (from 25% coverage in 2000) and Curdies. • Removal can disrupt ecosystem processes, long-term stability and resilience of the ecological community. • Loss of refuge and nursery function. • Impact on recruitment of estuarine and coastal marine fishes (and/or missing year classes) and macroinvertebrate fauna (e.g. the shrimp *Paratya*).	Newton (1994); Walsh & Mitchell (1995); Ierodiaconou & Laurenson (2002); right & Jones (2006); Waycott et al. (2009); (Dr P Carnell & Dr S Trevathan-Tackett pers. comm. November 2016)
Decline/loss of critical fish spawning cues, habitat and larval survival – black bream				
Black bream – Acanthopagrus butcheri (also applies to other fish species, e.g. estuary perch & marine southern anchovy)	• Black bream is apex predator of ecological community. • Completes entire life-cycle in stratified estuary.	• Recreationally important species. • Relatively long-lived (29y). • Spawning mainly occurs in salinities > 10 ppt and triggered by temperature above 15 °C. • In Hopkins most black bream eggs found at 14.9 – 17.5 °C and larvae at 12.6 – 17.5 °C	• Salinity structure linked to recruitment variability. • Identified link between flow and year class strength. • High levels of dissolved oxygen (DO) associated with typical spawning season.	Newton (1994, 1996); Morison et al. (1998); Nicholson et al. (2008); Jenkins et al. (2010); Williams et al. (2013)

Key Symptom/Indicator	Ecological role/Ecotype	Features	Impact	References
		• Spawning cued with salt-wedge emplacement phase and mass hatching of dormant copepod eggs, which provides abundant prey for newly hatched larvae.	• Eggs fail to hatch or larvae die in DO of 40% saturation or less.	
Decline/loss of biodiversity from viral pathogen epidemic of estuarine copepods				
Pathogen - iridovirus ZoopIIV [HR]	• Viral pathogen. • Infection found in at least three estuarine-endemic calanoid copepods – *Gladioferens pectinatus*, *Gippslandia estuarina* and *Sulcanus conflictus.*	• First detected in 2007 in Hopkins (and first record of virus in zooplankton). • Temperature a major driver of viral infection development (especially above 23 °C). • Primary location of discovery the Hopkins, but also observed in other estuaries within the EC including the Glenelg and Painkalac.	• Virus targets reproductive system leading to reproductive failure and/or morbidity of dominant estuarine-endemic copepods. • Infection of male and female *Gladioferens pectinatus* leading to limited recruitment. • Behavioural effects; limited escape response on disturbance, reduced swimming efficiency.	Williams et al. (2005); Roennfeldt (2013)

E5: Criterion 5 - Rate of continuing detrimental change.

Criterion 5 - Rate of continuing detrimental change			
Category	**Critically Endangered**	**Endangered**	**Vulnerable**
Its rate of continuing detrimental change is: as indicated by a) degradation of the community or its habitat, or disruption of important community processes, that is: or b) intensification, across most of its geographic distribution, in degradation, or disruption of important community processes, that is:	very severe	severe	substantial
5.1 An observed, estimated, inferred or suspected *detrimental change* over the *immediate*[#] past or projected for the *immediate* future of at least:	80%	50%	30%

[#] The immediate timeframe refers to10 years, or 3 generations of any long-lived or key species believed to play a major role in sustaining the community, whichever is the longer, up to a maximum of 60 years.

Eligible under Criterion 5 for listing as Vulnerable

Evidence

Eligibility under this criterion is about demonstrating an observed, estimated, inferred, or suspected ongoing detrimental change; where detrimental change may refer to either of the component of the criteria, that is to:

(a) changes in the geographic distribution of, or changes to populations of, critically important species; or

(b) degradation, or disruption of important processes.

Impacts of Climate Change – Sea Level Rise and Increasing Temperature

The Intergovernmental Panel on Climate Change's Fifth Assessment Report [AR5] (IPCC 2013) demonstrates that greenhouse gases, such as carbon dioxide and methane, have contributed significantly to a warming climate globally, in addition to other associated physical and chemical changes in the atmosphere, ocean and land surface – commonly referred to collectively as 'Climate Change'. There are several major consequences of climate change that threaten critical components of the ecological community, namely:

- rising sea level;
- increasing temperature;
- increasing ocean/coastal acidification; and
- declining and changed seasonality of rainfall.

These consequences all threaten to adversely affect the typical annual hydrological cycle of the salt-wedge, mouth condition of the estuaries, community integrity and ecological function.

1) Increasing rate of Sea Level Rise

Sea levels are rising due to thermal expansion of the oceans (from rising temperature) and the loss of ice from glaciers and ice sheets (Church et al. 2013a). They are expected to continue rising for centuries, even if greenhouse gas emissions are curbed and their atmospheric concentrations stabilised (Hunter 2012; Church & White 2011. Church et al. (2013b) report as part of IPCC AR5 that for RCP8.5 (i.e. the business as usual, high emissions scenario)[18] the rise by 2100 is 0.52 to 0.98 m, with the caveat that if there were collapse of marine-based sectors of the Antarctic ice sheet, this figure could rise by several tenths of a metre.

The estimated linear trend for the rate of sea level rise from 1900 to 2010 is 1.7 mm/year, with that estimated since 1961 being 1.9 mm/year (Church & White 2011). These trends are supported by more recent research and modelling, which indicates significant changes in the rate of sea level rise during the 20th century with the largest rates recorded since 1993 (CSIRO & BoM 2015; Masters et al. 2012). The latest IPCC report, AR5, states that a rate of 2.0 mm/year between 1971 and 2010 and 3.2 mm/year between 1993 and 2010, is very likely (Church et al. 2013b). Importantly, Church et al. (2013a) suggest that the increased rate of rise since 1990 is not part of a natural cycle but a direct response to increased radiative forcing (both anthropogenic and natural), which will continue to grow with ongoing greenhouse gas emissions. Grose et al. (2015) report that the rate of sea level rise during the 21st century will be larger than the average rate during the 20th Century as radiative forcing from greenhouse gas emissions continues to grow.

After accounting for and removing the effects of vertical land movements, natural climate variability, and changes in atmospheric pressure, sea levels have risen around the Australian coastline at an average rate of 2.1 mm/year over 1966-2009 and 3.1 mm/year over 1993-2009 (Grose et al. 2015). These observed rates of rise for Australia are consistent with global average values (White et al. 2014). Continued increase in sea level for the region of the ecological community (i.e. western and central Victoria) is projected with 'very high confidence' (Grose et al. 2015). Modelling has also demonstrated that over southern Australia, including the region of the ecological community, extreme sea level changes will be dominated by changes in mean sea level due to thermal expansion and ice sheet and glacier melt, rather than by changes in weather patterns (i.e. including wind-waves and storm surges) (Colberg & McInnes 2012; Hemer et al. 2013).

Projected sea level rise for the two extremes of the range of occurrence of the ecological community, the South Australian border to the west and South Point of Wilsons Promontory to the east, and the central region at Cape Otway, are given in Table E6. Given that sea level rise is tracking at the higher RCP rates (IPPC 2013a) it is likely that within the next decade or so, significant sea level rises of up to 180 mm can be expected, and within 30 years rises of up to 340 mm.

Sea level rise threatens to impact on the 'natural' intermittent nature of the estuary mouths within the ecological community. On Victoria's southern, micro-tidal coast, even small changes in sea level or wave height can cause significant changes in the location of sand deposition zones (Sherwood et al. 2008). Sand deposition is instrumental in determining the state of estuary mouths (McSweeney et al. 2017). Mouth status has been found to be one of three main factors determining the community structure and biomass of zooplankton in estuaries (i.e. the main source of secondary productivity), with freshwater inflow and water temperature being the other two factors (e.g. Froneman 2004; Hirst 2004). The location of the estuary mouths directly on the

[18] Representative Concentration Pathway (RCPs) are used by the Intergovernmental Panel on Climate Change (IPCC) as the full range of emissions scenarios used for the global climate model (GCM) simulations. For example, RCP4.5 represents a pathway consistent with low-level emissions, which stabilise the CO_2 concentration to about 540 ppm by the end of the 21st Century. RCP8.5 represents a high-emission scenario, for which the CO_2 concentration reaches about 940 ppm by the end of the 21st century (Grose et al. 2015).

coast means that sea level rise and associated storm surge events resulting from climate change will have maximum impact. There is little scope for avoidance of this impact as it is not possible to translocate or retreat landward, as might be possible for more terrestrially-based ecological communities (e.g. Oliver et al. 2012; Saintilan & Rogers 2013).

Table E6: Projected Sea Level Rise (mm) for the region of the ecological community under the RCP4.5 (i.e. intermediate emissions) and RCP8.5 (i.e. business as usual (high) emissions) scenarios (McInnes et al. 2015).

(RCP = representative concentration pathways or emissions scenarios used in climate model simulations). [Sea Level Allowance (mm), using the method of Hunter (2012), is the minimum distance required to raise an asset to maintain current frequency of breaches under projected sea level rise, and is given for the South Australian border].

Year		2030			2050			2070			2100		
Percentile		5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
South Australian border	RCP4.5	80	120	170	140	220	300	220	340	460	330	530	740
	RCP8.5	80	130	**180**	160	250	**340**	200	410	**560**	470	730	**1010**
Cape Otway	RCP4.5	70	120	160	130	210	290	200	320	450	310	510	710
	RCP8.5	70	120	**170**	150	240	**330**	260	400	**540**	450	710	**990**
Wilsons Promontory	RCP4.5	70	120	160	130	210	290	200	320	410	300	500	700
	RCP8.5	80	120	**170**	150	240	**330**	260	400	**540**	450	700	**970**
Sea Level Allowance (South Australian border)	RCP4.5	130			240			380			650		
	RCP8.5	140			270			470			930		

Rising sea levels are likely to lead to more frequent and eventually permanent breaching of estuary entrances, which would increasingly lead to marinisation of the estuarine systems with a loss of salinity stratification and a functional, dynamic salt-wedge cycle. They would also cause water levels to rise within the estuary (Sherwood 1988), and could potentially lead to changed morphology and flooding of adjacent wetlands.

Tidal connection, seawater inundation and its periodicity is a key ecosystem driver and, coupled with river input, is a major factor in determining the salinity regime and stratification of salt-wedge estuaries. True estuarine organisms are of necessity euryhaline, that is, they are adapted for optimal salinity ranges that are lower than the salinity of seawater. For example, in these Victorian estuaries, salinities may drop below 1 ppt for weeks at a time and rise to 30 ppt or more during low flow periods (Sherwood 1988). The ecological community is particularly vulnerable to the permanent marinisation of the water-column and loss of salinity stratification. A greater marine influence in estuaries will reduce the present variability experienced in estuarine salinity regimes within the ecological community, with salinities remaining near 30–35 ppt for longer periods.

2) Increasing rate of rising temperature

CSIRO & BoM (2015) have developed climate projections for Australia's NRM regions. Surface air temperatures in the Southern Slopes Cluster (which includes western and central coastal Victoria) have been increasing since national records began in 1910, and particularly since 1960, with mean temperature rising by 0.8 – 1.0°C (Grose et al. 2015). The rate of warming strongly follows the increase in global greenhouse concentrations (Grose et al. 2015). Australia will continue to warm substantially during the 21st Century, and warming will be large compared to natural variability in the immediate to near future (2030) and very large later in the century (by approximately 2090) (CSIRO & BoM 2015). By 2030 Australian annual average temperature is projected to increase by 0.6 – 1.3°C above the climate of 1986–2005.

Specifically for the extent of occurrence of the ecological community, between 1910 and 2013 daily maximum temperatures have increased by 1.0 – 1.1°C, with daily minimum temperatures increasing by 0.6 – 0.7°C (Grose et al. 2015). For 2030 (i.e. the immediate to near future) the annual warming across the Southern Slopes Cluster is projected to be 0.4 – 1.1°C (Grose et al 2015). Continued increases in mean daily maximum and daily minimum temperatures are projected for the region of the ecological community with 'very high confidence' (Grose et al. 2015). In general, projected warming is similar in all seasons, with some models simulating larger warming in summer and autumn.

Changes to temperature extremes often lead to greater impacts than changes to the mean climate (Grose et al. 2015). Heat related extremes are projected to increase at a similar rate as projected mean temperature with a substantial increase in the number of warm spell days. For example, the number of days over 35°C are projected to increase in western Victoria from 11°C currently, to approximately 13°C (between 12 and 15°C) by 2030 (RCP4.5) and to approximately 16°C (between 15 – 20°C) by 2090 (RCP4.5) or approximately 24°C (between 19 – 32°C) (RCP8.5) (Grose et al. 2015).

Water temperature in estuaries is strongly influenced by air temperature (Sherwood et al. 1987). For example in the Hopkins River estuary, winter minima of about 7°C and summer maxima of 25 – 30°C closely mimic average air temperatures (Newton 1994). Thus a rise in air temperature would be mirrored in changes to near-surface water temperature. In the deeper water of estuaries a greater seawater influence may moderate these increases due to both the smaller temperature variation of coastal seawater (13–19°C) and the expected time lag of 10–20 years for oceanic temperatures compared to air temperature (Sherwood 1988). In the Southern Slopes Cluster, the projected warming of sea surface temperature for 2030 under RCP8.5, for Portland in western Victoria is 0.3 – 0.8°C, while that for 2090 is 1.6 – 3.4°C (Grose et al. 2015).

Increased water and air temperatures will result in increased evaporation, particularly in shallow water bodies with relatively large surface areas, such as the estuaries of the ecological community. This may cause hypersalinity within the estuaries (Sherwood 1988). Monthly evaporation in the region of the ecological community is currently around 20 cm during summer and autumn (Sherwood et al. 1987).

Water temperature is highly influential in the function and integrity of the ecological community. The likely impacts of an increasing rate of increasing water temperatures from climate change are highlighted in Tables D1. Importantly, these changes are closely linked to changes in water chemistry, such as the solubility of oxygen, which decreases with increasing temperature. Declining oxygen levels in the water column would cause stress to fish and other organisms, as well as causing secondary changes to water chemistry such as the release of nutrients and toxicants (like hydrogen sulphide and ammonia) from the bottom sediments into the water column (EPA Vic 2011). If stratification breaks down and these nutrient-rich bottom waters mix with surface water, this can lead to an increase in algal blooms (including harmful blue-green algae).

Many estuarine organisms are sensitive to temperatures outside of their normal range. Thus increased temperature would affect physiological and behavioural functioning (e.g. growth, reproduction, migration) and could lead to mortality. Increased water temperatures would also impact on an organism's ability to deal with higher salinities, leading to physiological stress and potential mortality. It is expected that that while some species might favour the increased temperature (such as invasive pests), typical estuarine species adapted to specific ranges of temperature and salinity combinations would be unlikely to survive, resulting in significant changes to the composition of the ecological community. Plants and animals in the estuarine systems would face changes in food supply, competition, predation and disease. In particular, biota already stressed by poor water quality would be less able to cope with these additional pressures (EPA Victoria 2011).

Conclusion

The recent increase in the rate of sea level rise, from 1.7 mm/year to between 2.1 mm/year over 1966 – 2009 and 3.1 mm/year over 1993 – 2009 represents an increase of 24 percent and 82 percent (i.e. of between (2.1 – 1.7)/1.7x100% and (3.1 – 1.7)/1.7x100% respectively) over the recent past. The IPCC (AR5) further report that climate change-related sea level rise is projected to accelerate in the 21st Century (Church et al. 2013b) with similar rates projected for the region of the ecological community (i.e. Southern Slopes Cluster NRM region) (Grose et al. 2015).

This detrimental change represents a serious intensification of sea level rise across the ecological community's geographic distribution. The rate of continuing detrimental change in the ecological community is substantial as indicated by a serious intensification in the disruption of key drivers of important community processes, i.e. salt-wedge dynamics, salinity stratification, salinity regime and mouth condition.

Similarly, the rate of temperature rise, both atmospheric (which affects estuarine surface waters) and sea surface temperature (which affects seawater entering the estuaries of the ecological community), has intensified and is projected to continue rising at an increasing rate. In particular there has been a serious intensification since the 1960s. Temperature is a key driver of physiological and behavioural functioning of estuarine biota. Increases may lead to disruption of key ecological processes, such as primary and secondary productivity and nutrient cycling, and reproduction and recruitment. Therefore the ecological community is eligible for listing as **Vulnerable** under this criterion.

E6: Criterion 6 – Quantitative analysis showing probability of extinction

Criterion 6 - Quantitative analysis showing probability of extinction			
Category	**Critically Endangered**	**Endangered**	**Vulnerable**
A quantitative analysis shows that its probability of extinction, or extreme degradation over all of its geographic distribution, is:	at least 50% in the immediate future.	at least 20% in the near future.	at least 10% in the medium-term future.

Insufficient information to determine eligibility for listing under Criterion 6

There are no quantitative data available to assess this ecological community under this criterion. Therefore, there is **insufficient information** to determine the eligibility of the ecological community under this criterion.

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