State-wide assessment of fringing vegetation for the index of estuary condition

S.J. Sinclair, M. Kohout, K. Batpurev, D. Bryant, M. Bruce, A. Muir, J. Downe, P. Macak, D. Leevers, G. Brown.

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Acknowledgment

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it. We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

We are committed to genuinely partner, and meaningfully engage, with Victoria's Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond.

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Front cover photo: A sheltered arm of Mallacoota Inlet, near Gypsy Point (Steve Sinclair).

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State-wide assessment of fringing vegetation for the index of estuary condition

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Context:

The Index of Estuary Condition (IEC) was developed by the Victorian Government to improve estuary management by providing a means of assessing and scoring estuary condition. Several components of estuarine condition have previously been identified, along with metrics and indicators to quantify them. One component is the vegetation that fringes the estuary on its inland margin. This report details the application of the fringing vegetation condition metric to estuaries along the Victorian coast.

Aims:

This project aimed to assess the condition of the fringing vegetation around most of Victoria's estuaries (n=98). The estuaries included in the project were selected by DELWP's Water and Catchments Division.

Methods:

We assessed the condition of fringing vegetation using the metric described in a previous technical report (Sinclair and Kohout, 2018). The metric is composed of three indicators which can be assessed by field inspection or from estimates made based on aerial photographs and prior knowledge. The indicators are all based on maps which provide information about degradation across each estuary.

The indicators are:

1. **Percent of fringe covered by built structures**. Built structures include earthworks, dams, sealed roads and buildings. They are assumed to be detrimental because they remove fringing vegetation and disrupt the ecological processes that operate at the estuary perimeter. The higher the percentage of built structures, the lower the score.
2. **Nativeness of the fringing vegetation.** This indicator assesses the cover achieved by exotic plant species in the perennial fringing vegetation. Exotic species are assumed to be detrimental because they occupy niches otherwise occupied by native species. A lack of weeds confers a high score, conversely an abundance of weeds confers a low score.
3. **Structural complexity of the fringing vegetation**. This indicator compares the vegetation to a benchmark for theappropriate vegetation type, which specifies the cover of plants expected within each lifeform category. The vegetation is scored down if the expected lifeforms are absent or display insufficient cover.

These indicators are combined to produce a final score (between 0 and 100) for each estuary, which is expressed with the degree of uncertainty owing to incomplete on-ground assessment.

Results:

Among the 98 estuaries assessed, total scores for the fringing vegetation metric ranged from 55 to 100. For indicator 1 (built structures), 89% of estuaries scored >90/100, reflecting that most estuaries have small areas of built structures (though several are heavily developed). For indicator 2 (nativeness), the estuaries scored between 32 and 100, with a fairly even spread of scores across this range. For indicator 3 (structural complexity), all estuaries scored between 34 and 100, with a fairly even spread across this range.

Examples of estuaries are presented, which typify some of the main patterns of degradation.

Conclusions and implications:

The data provide an overview of the condition of estuary fringing vegetation across Victoria. Indicator scores for each estuary, along with the maps created to support the assessments, provide managers and decision makers with detailed information on where degradation has occurred and where values have been retained; across the state, and within each estuary. It is hoped that this information can assist future estuary management.

1 Introduction

1.1 Background and purpose

Estuaries occur where fresh water meets the sea at the mouths of rivers (Tagliapietra et al. 2009). Through them, many organisms, nutrients and pollutants move between rivers and the open ocean.

The Victorian Index of Estuary Condition (IEC) has been developed by the Victorian Government to quantify the ecological condition of Victorian estuaries and improve their management (Annett and Adamson 2008). It aims to-

- report periodically on the ecological condition of estuaries in Victoria,
- assist prioritisation of management investment among estuaries, and
- provide a baseline for assessing long-term and large-magnitude changes in resource condition.

These goals will be accomplished by measuring a series of indicators at estuaries across Victoria, and combining them to form a condition score for each estuary. The IEC has five components: physical form, hydrology, water quality, flora and fauna (Arundel et al. 2009, Woodland and Cook 2015). Indicators and sampling protocols have been developed, trialled and appraised for each (Warry and Reich 2013, Pope et al. 2015; Woodland and Cook 2015, Sinclair and Kohout 2018).

Fringing vegetation is recognised as an essential component of the ‘flora’ theme and is served by its own condition assessment method (Sinclair and Kohout 2018). This report details the results of the first state-wide assessment of fringing vegetation using that method, which was applied to ninety-eight of Victoria’s estuaries between 2017 and 2019.

1.2 Estuarine fringing vegetation

‘Estuarine fringing vegetation’ is the vegetation that occupies the zone above the permanently inundated portion of an estuary, but which experiences some hydrological influence from the salty waters of the estuary. Estuarine fringing vegetation may be inundated or waterlogged periodically, by tides and/or flows from the catchment. In many estuaries, the fringing vegetation occupies a broad flat area subject to flooding, which is referred to here as the ‘estuarine floodplain’.

Each estuary in Victoria supports unique fringing vegetation (Sinclair and Sutter 2008, Osler et al. 2010, Victorian Saltmarsh Study 2011, Boon et al. 2015). This is due to variation in geomorphology and rainfall across the Victorian coast, which influence the physical form, hydrology, soil type, water quality and sediment load of estuaries (Roy et al. 2001; Pope et al. 2015). In Victoria, all estuaries have some combination of a few common vegetation types: mangroves, coastal saltmarsh, ephemeral pool vegetation, marshlands with tall emergent grasses and grass-like plants, and woody swamp scrubs. These vegetation types occur singly or together, in large or small quantity, depending on the local characteristics of each estuary.

Some estuaries of relatively minor streams surrounded by relatively steep terrain have only tiny strips of fringing vegetation (e.g. Sherbrook River near Port Campbell) while other estuaries are surrounded by thousands of hectares of fringing vegetation on extensive estuarine floodplains (e.g. the Barwon River near Ocean Grove).

Fringing vegetation is an important consideration in the assessment of estuary condition. It has inherent value, along with habitat value for many species (Hindell and Jenkins 2004; Nagelkerken et al. 2008), and functional value due to the roles it plays in mediating the flows of water, nutrients, toxins and organisms that move through the estuary (Tagaza 1995; Mondon et al. 2009; Victorian Saltmarsh Study 2011).

Fringing vegetation may be degraded by many human activities, which often interact in complex ways (Barton 2003, Barton et al. 2008, Victorian Saltmarsh Study 2011, Boon et al. 2015). Significant threats include climate change and sea level rise (Prahalad et al. 2011; Osland et al. 2016), hydrological changes that affect tidal inflow or streamflow, clearing for development or agriculture (Kennish 2002, Barbier et al. 2011), eutrophication (Bertness et al. 2002), livestock grazing (Sinclair and Sutter 2008), and invasion by exotic plants (Callaway and Josselyn 1992; Hurst and Boon 2016).

Sinclair and Kohout (2018) provided a more detailed overview of the variation of vegetation types that occur in the estuarine fringe, their ecological values and the processes which threaten them.

1.3 Measuring ecological condition

The following definition of condition is used here, which is consistent with all relevant Victorian policies and tools – such as Habitat Hectares (Parkes et al. 2003, DSE 2004), Index of Wetland Condition (IWC, DSE 2005a, 2009, DELWP 2016a, 2016b) and Index of Stream Condition (ISC, DSE 2005b).

Ecological condition measures the degree of retention (or loss) of those ecological attributes that characterise an ecosystem in its desired state.

The ‘desired state‘ is generally characterised by the following attributes:

- It is relatively undisturbed by post-European human activity and resembles the system ‘pre-1750’.
- It is able to support maximally-complex ecological communities, structures and networks, given the systemic constraints on primary production.
- It may have valuable ecological elements which take time to form.
- It has no invasive or exotic species.
- Its natural ecological and geomorphological processes continue to operate, including spatial links with other systems and regions.

Ecological condition can be quantified by a condition metric (or index). Condition metrics quantify the degree of difference between the desired state and the actual site being assessed. The attributes which characterise the desirable state are usually expressed by a ‘benchmark’ (or ‘reference state’, ‘baseline’) (Parkes et al. 2003, Parkes and Lyon 2006, Gibbons and Freudenberger 2006, Stoddard et al. 2006). The 'reference' approach has a long history of development and application in freshwater wetlands, especially in the USA (e.g. Brinson 1993, USDA 2008).

Sinclair and Kohout (2018) discuss the conceptual issues and design requirements of condition metrics in more detail.

2 Methods

2.1 Summary of the assessment method

The assessment method was described in Sinclair and Kohout (2018). This section provides a brief summary of that method, but readers are referred to the original report for more details on its development, justification and testing.

The metric produces a score (0–100) that quantifies the condition of fringing vegetation in an estuary. The score represents how far a given estuary deviates from the desired state of that estuary. The score is intended to reflect the condition of that estuary in relation to others, and to accord with expert views on estuary condition.

In order to calculate a condition score, the metric requires a map which represents the following, as polygons, for each estuary:

- The full extent of the fringing vegetation, as it occurred prior to modern land use impacts,
- The coverage of any built structures that impinge on the fringing vegetation,
- The coverage of all vegetation types (Ecological Vegetation Classes, EVCs),
- Zones within each EVC which are in a consistent condition state; conceived in terms of vegetation structure and weed invasion,
- The estimated cover of weeds within each of these zones, and
- The cover of defined plant lifeforms within each of these zones.

This information is assessed by field inspection where access is possible. Where access is not possible, this information is estimated, using aerial imagery and analogy to known areas.

The metric uses this information to calculate scores for three indicators, each of which is scored on a 0–100 scale:

1. **Percentage of fringe area that is covered by built structures.** The higher the percentage of built structures, the lower the score. Built structures are assumed to be detrimental because they remove fringing vegetation and disrupt ecological processes.
2. **Nativeness of the fringing vegetation.** This indicator assesses the degree of cover achieved by the invasion of exotic plant species in the fringe. Exotic species are assumed to be detrimental because they occupy niches otherwise occupied by native species and may alter the structure of the vegetation as habitat or its ecological function. A lack of weeds confers a high score, an abundance of weeds confers a low score.
3. **Structural complexity of the fringing vegetation.** This indicator assesses whether the fringing vegetation possesses the mix and cover of life-forms that would be expected to be prominent, given the EVCs that are present. This indicator produces a score that is calculated with reference to benchmarks specific to each EVC.

An over-all score representing the condition of fringing vegetation (0-100) is calculated by taking the average of these three indicator scores.

This over-all score is expressed with the uncertainty that is attributable to incomplete survey (which is considered a major component of uncertainty; Sinclair and Kohout, 2018). This is calculated on indicators 2 and 3 only (it is assumed that built structures are obvious, even on aerial imagery, and no uncertainty stems from whether they were directly observed). All un-observed polygons are assigned values that produce the worst possible score (100% exotic cover; none of the benchmark lifeform groups). A new overall score for the whole estuary is calculated using these scores, representing the lower bound for that estuary. A similar process is repeated with the highest score possible for each un-observed polygon to derive the upper bound.

The following sections provide a detailed description of how this process was implemented across Victoria's estuaries.

Coverage of assessments

2.1.1 Estuaries assessed

The estuaries to be assessed were selected by DELWP's Water and Catchments Division. Almost all Victorian estuaries were included (n=98, Figure 1, Table 1,). The estuarine fringe areas range in size from less than 1 ha (several small estuaries) to 4533 ha (Snowy River). For assessment purposes Deep Creek and Cardinia Creek were considered a single estuary, because the construction of channels has made it impossible to distinguish these two near-neighbours from each other. Two of the assessed estuaries are divided into sub-estuaries:

- the Tarwin estuary (also known as Andersons Inlet) has several smaller distinct estuaries connected to the estuary (Pound Creek, Screw Creek, Tarwin River proper).
- the Merri River estuary has two sections (partly as a result of channelisation works), with two different mouths (one at Stingray Bay in Warrnambool, the other further west at the western end of Rutledges Cutting near Tower Hill).

In this report both the Tarwin and the Merri are reported as individual estuaries (but the accompanying GIS data includes additional data on each sub-estuary).

Four estuaries that have been assessed under other IEC components have been excluded from the fringing vegetation assessment (Elwood Canal. Paterson River, Yallock Drain, Lang Lang River). These estuaries are entirely artificial. This means that they have no pre-impact fringe area, and the formulae used to calculate a score cannot do so because they cannot include zero as a denominator (in other words, no impact can be registered if there was nothing to impact). These estuaries are excluded from further discussion here.

2.1.2 Survey coverage and effort

The fringing vegetation condition assessment was intended to be a 'rapid assessment'. Guided by this, Sinclair and Kohout (2018) gave guidance about the appropriate assessment effort. We followed this guidance, summarised as follows:

- Estuaries with a fringe area <500 ha were assessed by a pair of observers spending <1 day in the field.
- No more than 3 days was spent in the field to assess any single estuary. The only estuaries that took 3 days were Mallacoota Inlet, Jack Smith Lake, the Barwon River and the Tarwin River.

Some estuaries are difficult to access due to their remote locations or because they are on private land. We made reasonable efforts to visit as many patches as possible in each estuary. We tried to visit an example of every EVC and every land use type within each estuary, but we did not always succeed.

Where necessary, we visited private properties, using contact information provided by CMAs, Landcare and Trust for Nature (given with prior permission of the landholders), or by seeking permission via door knocking or letterbox dropping. We also used kayaks to access places that could not otherwise be visited. Table 1 provides a summary of the access gained to each estuary. We believe that this coverage is adequate to allow us to make informed estimates of the status of the remaining areas, and to thus form a reasonable overview of the status of all estuaries assessed.

2.1.3 Assessment dates

All field assessments were undertaken between September 2017 and October 2019, with most assessments in 2018 (Table 1). Importantly, this was before the extensive fires that burnt large areas in East Gippsland in 2019-2020, including estuarine floodplain vegetation in some cases. This means that for many estuaries, the plant cover estimates are unlikely to be relevant immediately post fire. The estuaries known to be affected are indicated in Table 1.

2.1.4 Desktop assessments

Some estuaries are difficult to access as they are in remote locations or occur largely on private land. Given this, it was agreed with DELWPs Water and Catchments Division that some estuaries would only be assessed by aerial photograph, with all vegetation cover being estimated via analogy with similar places that were observed. Table 1 shows which estuaries were nominated for a desktop only assessment.

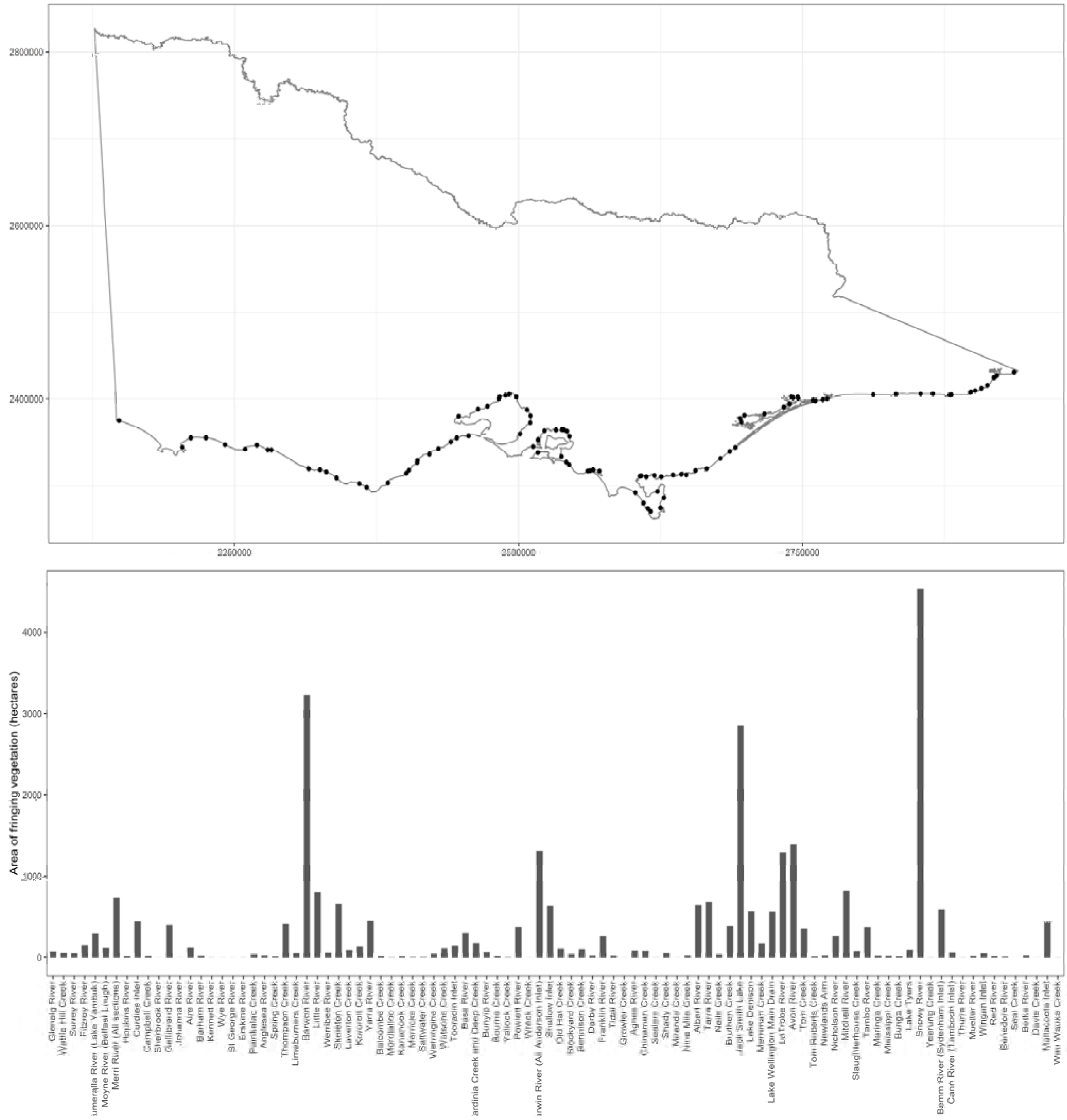

Figure 1. A. Locations and B. sizes of the estuaries assessed.

Table 1. Summary of field surveys

The estuaries are listed from west to east along the Victorian coast. The area of their fringe is reported in hectares, with green shading used to accentuate the values, and highlight the very large estuaries. 'Percent area observed' records the percentage of the fringe area covered by polygons that were actually inspected in the field, with the intensity of green shading used to accentuate the values. 'Access' records how many private properties were accessed (numbers), and whether a kayak was used (K). The date of field assessments is provided. Estuaries affected by the 2019-20 East Gippsland fires are marked #.

Estuary	Fringe Area (Ha)	Percent area observed	Access	Assessment Date
Glenelg River	78.5	40		Dec 2018
Wattle Hill Creek	57.2	100		Nov 2018
Surrey River	52.8	99	K	Nov 2018
Fitzroy River	148.5	100	2	Nov 2018
Eumeralla River (Lake Yambuk)	300.6	16	1	Aug 2018
Moyne River (Belfast Lough)	117.8	36		Aug 2018
Merri River (All sections)	734.7	11		Aug 2018
Hopkins River	10.1	24		Aug 2018
Curdies Inlet	447.8	100	1	Aug 2018
Campbell Creek	13.6	100		May 2018
Sherbrook River	0.8	100		May 2018
Gellibrand River	403.5	100	1	Aug 2018
Johanna River	0.5	100		May 2018
Aire River	121.2	100	2	Aug 2018
Barham River	17.9	26		May 2018
Kennett River	1.3	68		May 2018
Wye River	0.2	100		May 2018
St George River	0.7	100		May 2019
Erskine River	1.1	100		May 2019
Painkalac Creek	42.1	55		May 2019
Anglesea River	24.0	97		Oct 2017
Spring Creek	8.1	72		May 2018
Thompson Creek	414.5	39		Oct 2017
Limeburners Creek	54.6	100		Aug 2018
Barwon River	3229.5	30		Oct 2017
Little River	803.5	Desktop		NA
Werribee River	63.3	Desktop		NA
Skeleton Creek	662.3	Desktop		NA
Laverton Creek	97.2	Desktop		NA
Kororoit Creek	134.1	Desktop		NA
Yarra River	456.0	Desktop		NA
Elwood Canal	No fringe	Desktop		NA
Balcombe Creek	11.5	100		Oct 2019
Mordialloc Creek	3.3	Desktop		NA
Kananook Creek	9.0	Desktop		NA
Paterson River	0.5	Desktop		NA
Merricks Creek	4.9	100		Oct 2019
Saltwater Creek	4.7	Desktop		NA
Warringine Creek	47.2	Desktop		NA
Watsons Creek	114.3	Desktop		NA

Estuary	Fringe Area (Ha)	Percent area observed	Access	Assessment Date
Tooradin Inlet	143.4	Desktop		NA
Bass River	304.0	Desktop		NA
Cardinia Creek and Deep Creek	179.9	Desktop		NA
Bunyip River	71.9	Desktop		NA
Bourne Creek	12.3	70		Apr 2019
Yallock Creek	4.1	Desktop		NA
Yallock Drain	1.3	Desktop		NA
Powlett River	380.5	42	2	Apr 2019
Lang Lang River	0.1	Desktop		NA
Wreck Creek	0.5	100		Sep 2018
Tarwin River (All Anderson Inlet)	1309.1	36		Sep 2017
Shallow Inlet	634.4	40	1,K	Sep 2018
Old Hat Creek	110.4	18		Mar 2019
Stockyard Creek	44.1	74		Sep 2017
Bennison Creek	106.6	45	1	Mar 2019
Darby River	23.1	75	K	Aug 2018
Franklin River	264.8	21		Sep 2017
Tidal River	21.3	67	K	Sep 2018
Growler Creek	0.4	Desktop		NA
Agnes River	90.4	Desktop		NA
Chinaman Creek	87.2	Desktop		NA
Sealers Creek	1.5	Desktop		NA
Shady Creek	55.0	0		NA
Miranda Creek	0.3	Desktop		NA
Nine Mile Creek	24.3	0		NA
Albert River	642.3	35	1,K	Mar 2019
Tarra River	687.3	40	K	Mar 2019
Neils Creek	40.8	62	1	Mar 2019
Bruthen Creek	394.0	69	K	Sep 2018
Jack Smith Lake	2851.9	49		Sep 2018
Lake Denison	575.0	25	1	Mar 2019
Merriman Creek	176.0	100		Sep 2018
Lake Wellington Main Drain	570.0	83		Sep 2018
LaTrobe River	1290.6	97		Sep 2018
Avon River	1391.7	54		Sep 2019
Tom Creek	357.2	32		Mar 2019
Tom Roberts Creek	8.3	0		NA
Newlands Arm	23.8	54		Mar 2019
Nicholson River	266.3	9		Mar 2019
Mitchell River	819.0	4		Mar 2019
Slaughterhouse Creek	84.4	80		Mar 2019
Tambo River	378.4	21		Mar 2019
Maringa Creek	20.3	53		Aug 2019
Mississippi Creek	16.7	29	1	Aug 2018
Bunga Creek	8.5	100		Aug 2018
Lake Tyers	100.0	73		Aug 2018

Estuary	Fringe Area (Ha)	Percent area observed	Access	Assessment Date
Snowy River	4533.3	36	2	Aug 2018
Yeerung Creek #	1.1	0		NA
Bemm River (Sydenham Inlet) #	594.8	30	K	Sep 2018
Cann River (Tamboon Inlet) #	65.8	76	K	Sep 2018
Thurra River #	1.4	100		Jan 2018
Mueller River #	13.9	0		NA
Wingan Inlet #	52.1	78	K	Aug 2018
Easby Creek #	No fringe	Desktop		NA
Red River #	11.1	Desktop		NA
Benedore River #	7.4	Desktop		NA
Seal Creek #	No fringe	Desktop		NA
Betka River #	25.8	96	K	Aug 2018
Davis Creek #	0.9	100		Aug 2018
Mallacoota Inlet #	444.0	65	1,K	Aug 2018
Wau Wauka Creek #	1.4	Desktop		NA

2.2 Delineation of the fringing vegetation

Assessment requires that the pre-colonial extent of the fringing vegetation is defined spatially. This included:

- all of the estuarine portions of the pre-'1750 intertidal zone' defined by the Victorian Saltmarsh Study (2011) and further described in Sinclair and Boon (2012), which included information from historic maps, and
- all wetlands or damplands which show a 'brackish influence' in their species composition, AND which are contiguous with the flats of the estuary (i.e. excluding any nearby saline wetlands which are separated by raised ground, dunes, etc.). This includes areas that have expanded since colonisation (See below, Delineation of the fringing vegetation; Treatment of estuaries that have shifted location).

In many cases, the extent of the fringing vegetation is obvious, due to a definite change in elevation and slope. In some cases, however, the natural landward boundary of the fringing vegetation may be ambiguous, and is particularly difficult in three situations:

- When estuaries are contiguous with extensive freshwater wetlands (e.g. the Glenelg estuary and Long Swamp),in which case detailed searches must be made to understand the distribution of the 'brackish influence' (see below, the use of salt indicator species).
- When portions of the fringing vegetation are now hydrologically disconnected form the estuary by human impacts such as sea walls and roads (e.g. portions of the Tarwin estuary inland form the seawall), in which case the vegetation may no longer provide an accurate indication of estuarine conditions, and historical inference must be used.
- When the fringe has been covered by built structures (e.g. much of the fringe of the Yarra which is covered by infrastructure; much of the fringe of the Little River, which is covered by the artificial waterbodies of the Western Treatment Plant), in which case historical data must be used.

The seaward boundary may also be difficult to determine. For estuaries or portions of estuaries that are fringed by mangroves, the seaward margin of the mangroves was considered the lower boundary of the fringing vegetation (i.e the mangroves are included). For estuaries lacking mangroves, the lower boundary of the fringing vegetation was defined by the regular low tide line. Seagrass vegetation was always excluded from the fringing vegetation, even if it was exposed at the time of assessment. Water Matts and Tassels (*Ruppia* and *Lepilaena* species) were included when growing in pools surrounded by intertidal vegetation, but otherwise excluded.

The use of salt-indicating plant species

A small number of perennial plant species was used to delineate the upper limits of estuaries and exclude upstream freshwater riparian or floodplain areas. Wherever the species listed in Table 2 occurred, it was assumed that the vegetation was under some salty influence.

The use of plant species to delineate the salty zone of influence is considered more appropriate than using direct measures of water or soil salinity, because those measures may change from day to day, whereas the presence of a perennial plant implies that conditions have been suitable for a reasonably lengthy period of time; sufficient for that species to establish, grow and compete.

The species in table 2 were compiled from the experience of the authors. Species which routinely inhabit both salty or fresh conditions are not included, since these species do not help estuary delineation (notably including Common Reed *Phragmites australis*). Many other species are also indicative of salty conditions but are not sufficiently common to be useful as indicators.

Table 2. Species of plant indicative salty conditions

Scientific name	Common name	Generalisation of salt tolerance
Apium prostratum	Sea Celery	Saline – Brackish (rarely fresh)
Avicennia marina	Grey Mangrove	Saline
Bolboschoenus caldwellii	Sea Club-sedge	Brackish
Distichlis distichophilla	Australian Salt-grass	Saline - Brackish
Disphyma crassifolium	Rounded Noon-flower	Saline - Brackish
Ficinia nodosa	Knobby Club-sedge	Brackish (rarely fresh)
Frankenia pauciflora	Southern Sea-heath	Saline
Gahnia filum	Chaffy Saw-sedge	Saline - Brackish
Gahnia trifida	Coast Saw-sedge	Brackish (rarely fresh) and usually Calcareous
Juncus kraussii	Sea Rush	Saline - Brackish
Pratia irrigua	Salt Pratia	Brackish
Samolus repens	Creeping Brookweed	Brackish
Sallicornia spp.	Glassworts	Saline
Selliera radicans	Shiny Swamp-mat	Brackish
Tectocornia spp.	Glassworts	Hypersaline - Saline
Triglochin striata	Streaked Arrow-grass	Saline - Brackish (rarely fresh)

Treatment of estuaries that have shifted location

In some cases, estuarine vegetation has expanded into areas where it did not originally occur. This has happened in the following circumstances:

- When channels are cut which link previously isolated wetlands to the estuary, causing freshwater wetlands to become salty and for estuarine species to extend into them. This has occurred on the Merri River. Such areas are included, and when the score is calculated they may offset other areas that have been lost.
- The engineering of a permanent opening between the Gippsland Lakes and the sea at Lakes Entrance has caused the lakes to become more saline (Boon et al, 2008; Sinclair and Boon, 2012). This has led the expansion of brackish wetlands around the margins of the lakes, and up the streams which drain into them. Given these river-mouths are here considered to be estuaries, this has led to the creation of new estuarine fringing vegetation. This has occurred on many of the rivers

flowing into the Gippsland Lakes, notably the Avon and the LaTrobe. Such areas are included, and when the score is calculated they may offset other areas that have been lost.

- When entirely artificial estuaries are created through coastal drainage, and estuarine vegetation begins to form on sediments deposited along the edge of the channels. This leads to patches of estuarine fringe forming where previously there was dry land. Such areas are normally very small, such as those patches of marshland which have formed along the Paterson River (an artificial river). As noted above, artificial "estuaries" are excluded from the data presented in this report.

Estuarine fringing vegetation may also retreat from areas where conditions become unsuitable. This has not happened extensively in Victoria and has barely impacted on the assessments presented here. Three mechanisms can lead to the retreat of the estuarine fringe:

- Sea level rise may cause open sea water to extend further into the estuarine fringe (e.g. Mangrove dieback at the seaward edge).
- Decreases in stream-flow (or seepage) due to low rainfall or impoundments may lead to the drying of the estuarine fringe, and invasion by terrestrial species.
- The introduction of freshwater flows into the estuarine fringe (e.g. storm water outlets) may cause the estuarine fringe to be overtaken by freshwater wetlands. This has occurred to a small extent in the Karaaf wetland, part of the Thompson Creek estuary.

In all such cases of gains or losses to the estuarine fringe, the following rules have been applied:

- Newly formed estuarine fringe is included when the area of the fringing vegetation is calculated. It is scored for components 2 and 3, and contributes to the final score.
- Built structures on areas of new fringe are ignored. Built structures cannot reduce the score by removing areas that were not originally present.
- Areas of fringe which have disappeared through the retreat of estuarine species are counted as fringe, and scored against the EVC that best matches their context in the landscape.
- Areas of fringe which have disappeared as a result of built structures are treated as described above (Indicator 1).

These rules are intended to strike a balance between two considerations:

- Acknowledging that estuaries may expand and be restored, and ensuring this is reflected in an increased score.
- Acknowledging that losses should not be forgotten, and ensuring that this is reflected in a decreased score.

Delineating the area estuarine influence when estuaries meet intertidal coastal zones

For estuaries that meet extensive coastal intertidal zones it is difficult to determine where the estuary fringe ends and the coastal intertidal zone begins (e.g. Corner inlet, Westernport Bay).

In these cases we defined the fringe as being that area of intertidal vegetation within a certain distance from the stream. This area was defined on the GIS by applying a buffer. The width of the buffer was determined by the flow in each stream. This is based on the assumption that high-flow streams would exert more influence on the coastal zone than low-flow streams. The buffer size was calculated as follows:

- The expected total annual rainfall was assigned to each pixel (75 m) in south eastern Australia.
- Flow accumulation was modelled Using the SAGA Flow Tracing Tool (Conrad et al. 2015). In this process, each pixel sheds its rainfall to the least-elevated of the 8 adjacent pixels. This process occurs sequentially, with low-lying pixels accumulating rainfall from more-elevated pixels, until every pixel is assigned its own rainfall plus the rainfalls of all ‘upstream’ pixels. This method does not need any input that describes catchments, which are discovered automatically by the process. Elevation data were taken from the NASA Shuttle Radar (Geoscience Australia 2011).
- Once the flow accumulation was defined for all pixels in Victoria, the DELWP estuary spatial layer was used to select all pixels within each estuary (this layer includes the aquatic portion of each estuary including its mouth). The maximum value of all these pixels is taken as the ‘relative accumulated flow’ for each estuary. The value is expressed as a relative value (i.e. lacking units), because it depends on the pixel size used in the computation, which is arbitrary. The values were standardised so that the estuary which accumulated the least flow of any in Victoria was assigned a value of 1 (Wye River, with a small catchment).
- The magnitude of the relative accumulated flow varies over 30-fold among the relevant estuaries. To dampen this and ensure that the resultant buffers do not differ by many orders of magnitude, the log10 of the relative accumulated flow value was taken.
- The log10 relative accumulated flow was used as a weight to create appropriate buffers. It was arbitrarily decided that a reasonable set of buffers results from multiplying the log10 relative accumulated flow by 20.

The resultant buffer distance is shown in Table 3, for all estuaries where this approach was taken (15 of 98). Those estuaries not shown in Table 3 did not require a buffer. In Sinclair and Kohout (2018), 21 estuaries were flagged as needing a buffer to delineate their fringe; however detailed consideration of six of these estuaries revealed obvious natural boundaries, and the buffer method was not implemented.

It is important to note that the flows calculated with this method ignore impoundments, and thus provide a “pre-1750” view of flows. This is appropriate in the context of the IEC fringing vegetation assessment, which uses the pre-1750 conditions as a benchmark.

While this method provides a repeatable relative means for setting buffers which relate to flows, it is acknowledged that it does not accurately represent the actual flow at the mouth of each estuary. The actual flow will be influenced by other complex processes including groundwater interactions, evaporation and soil infiltration. Similarly, we do not claim that this method identifies an unequivocal boundary between estuarine influence and the intertidal coast; it merely provides a transparent solution to a subjective problem.

Table 3. Buffers used to delineate the estuarine fringe from a continuous intertidal zone

Estuary	Relative accumulated flow	Relative accumulated flow (log10)	Buffer (m)
Neils Creek	8	3.42	68
Stockyard Creek	31	5.71	114
Nine Mile Creek	593	10.58	212
Bennison Creek	1,403	12.01	240
Bunyip River	2,129	12.70	254
Warringine Creek	3,405	13.48	270
Shady Creek	3,485	13.52	270
Old Hat Creek	4,960	14.10	282
Watsons Creek	12,078	15.57	311
Agnes River	16,968	16.14	323
Franklin River	26,054	16.85	337
Tarra River	44,223	17.73	355
Albert River	65,537	18.38	368
Cardinia Creek & Deep Creek	74,128	18.58	372

2.3 Assigning Ecological Vegetation Classes

2.3.1 General approach

DELWP curates the EVC typology for Victoria and provides EVC descriptions and indicative species lists for most EVCs. There is, however, no repeatable method for deciding which EVC applies to a given stand of vegetation. We consulted the EVC descriptions provided in the following sources, and applied the EVC that best fitted each polygon in the dataset, based on that polygons species composition, inundation regime and place in the landscape. In most cases EVC assignation was clear and unambiguous.

- DSE (2012). A field guide to Victorian Wetland Ecological Vegetation Classes for the Index of Wetland Condition. This document describes some of the relevant EVCs.
- DELWP (2016b). Benchmarks for wetland Ecological Vegetation Classes in Victoria. This document provides descriptions for all estaurine EVCs in Victoria, with example photographs and species lists.
- Victorian Saltmarsh Study (2011). Mangroves and coastal saltmarsh of Victoria: distribution, condition, threats and management. This document provides more detailed descriptions of the estuarine EVCs that are intertidal, including photographs and species lists.

As described in these resources, many of the most widespread estuarine EVCs are characterised by the dominance of one or a few species. Thus, species can often provide a short hand to the EVC. Table 4 shows the species – EVC relationships our field teams relied on to identify EVCs in many cases.

Table 4. Species used to help identify some obvious EVCs

Dominant species	EVC
Juncus kraussii	Estuarine Wetland
Avicennia marina	Mangrove Shrubland
Bolboschoenus caldwellii	Brackish Sedgeland
Disphyma clavellatum	Coastal Dry Saltmarsh
Frankenia pauciflora	Coastal Dry Saltmarsh
Melaleuca spp.	Estuarine Scrub
Gahnia filum	Coastal Tussock Saltmarsh
Tectocornia arbuscula	Wet Saltmarsh Shrubland
Tectocornia halocnemoides	Coastal Hypersaline Saltmarsh
Tectocornia pergranulata	Coastal Hypersaline Saltmarsh

2.3.2 Difficult cases

Systems undergoing change

When the hydrology of an area is altered, the vegetation may undergo rapid changes. An EVC may be difficult to assign in such places.

By far the most common situation where change was occurring was where Estuarine Scrub was flooded beyond the tolerance of the dominant shrub species, and these were declining. In most cases this vegetation was changing into Estuarine Reedbed (dominated by Common Reed *Phragmites australis*) or Estuarine Wetland (dominated by Sea Rush *Juncus kraussii*). We scored such areas as Estuarine Scrub where the shrub stems (dead or alive) were still present at a density of more than ~1 per 4 m^2.

For all other instances of change – often where the causal mechanism was unclear- we applied the following general principle: an area undergoing change was not penalized if the change is from one assemblage of native species that is recognizable as an estuarine EVC, to another that is also recognizable as an estuarine EVC. We selected whichever EVC would return the highest score when assessed. If, however, the change was from a recognisable estuarine EVC to some other assemblage of plants (e.g. exotic vegetation, a freshwater wetland EVC, a terrestrial EVC), then the EVC for the original vegetation was used, and the patch scored down accordingly.

Highly degraded systems

The identification of EVCs is based on the characteristics of the site (soil, inundation regime, etc) and the plant species present (dominant species, species which indicate certain conditions). In some places these characteristics have been changed dramatically by human land use; including the removal of most or all of the vegetation, and the alteration of the inundation regime. By the logic of the metric, such places are degraded, and must be scored accordingly by assigning them a prior EVC, and quantifying how far they now deviate from this EVC. This is often difficult without the cues that are usually used for identification. In these cases we:

- Used any intact vegetation patterns in the adjacent landscape, and subjectively extrapolated them into the degraded area based on elevation, slope and soil type.
- Assumed that the few remaining species indicated the prior EVC (See Table 4).
- Used historical records (such as Parish Plans), which sometimes distinguish marshland, saltmarsh and estuarine scrub.

We cannot, however, claim that our reconstructions of EVCs in cleared landscapes were without error.

2.4 The data

2.4.1 Presentation of data

This report is accompanied by a GIS dataset and a file summarising all of the scoring details.

A set of maps, one for each estuary, has also been provided. These were prepared as part of the assessments for the submerged vegetation component of IEC (Woodland and Cook 2015). For clarity, these show only the fringing vegetation indicators 1 and 2 (Built structures and Nativeness).

2.4.2 Variables recorded but not scored

The following additional variables were collected but not used to derive a quantitative score. These variables were discussed in Sinclair and Kohout (2018). They provide information that may be useful for managing estuaries and tracking changes in estuarine ecology, but are difficult to quantify without excessive effort, or without perverse scoring outcomes in some cases.

- The health of the five most common plant species, assessed on a percentage scale, taking into account the 'degree of health' expected at the specific time of year for the species.
- The extent of engineered hydrological modifications was recorded, by simply assessing whether any of the following modifications are impacting on the estuary:
    - Sea walls (or equivalent built infrastructure) restricting tidal inflows
    - Culverts restricting tidal inflows
    - Artificial freshwater inputs directly into the estuary.
    - Dams or culverts restricting stream flow into the estuary, within 100m of the estuary perimeter.

These variables are not reported on further here but are included in the accompanying data for each estuary.

3 Results

3.1 The condition of Victorian estuaries

3.1.1 State-wide overview

The total score for each estuary varied between 54 (Shallow Inlet) and 100 (Miranda Creek) (Figures 2 and 3). The scores for the individual indicators varied more widely:

- **Percent of fringe covered by built structures**. Most (87 of 98) estuaries scored >90. This reflects the fact that built structures are generally small, and even estuaries which experience significant human uses are often impacted by structures with relatively limited footprints compared to the extent of the estuarine floodplain (boat ramps, carparks, etc). In contrast, a few estuaries have been heavily impacted by urban and industrial impacts, resulting in very low scores (e.g. The Yarra River with a score of 0.7).
- **Nativeness of the fringing vegetation**. All estuaries scored between 32 and 100, with a fairly even spread of scores across this range. The fact that all estuaries score at least 32 reflects the fact that all estuaries in Victoria retain some areas free from serious weed invasion, since there are currently relatively few weeds that tolerate saline conditions (Saltmarsh Study, 2011). The relatively even spread of scores presumably reflects the varying patterns of clearing for agriculture in different estuaries, and the incremental nature of weed invasions.
- **Structural complexity of the fringing vegetation.** All estuaries scored between 34 and 100, with a fairly even spread across this range. This reflects the fact that structural degradation is an incremental process.

The fact that the range of the total scores contracted in comparison to the individual components reflects the fact that no estuary scored poorly across all indicators; in other words, different estuaries have lost and retained condition in different ways.

There are some regional patterns in condition scores (evident in Figures 2 and 3, where the estuaries are ordered west to east). For example, estuaries in East Gippsland generally have very high scores, which relates to their position in a remote landscape, many within National Parks. In contrast, the estuaries of south Gippsland (from Powlet River to Bennison Creek) tend to have the lowest scores, which relates to their position in an agricultural landscape.

However, regional patterns are generally not prominent, and the data highlight the fact that all estuaries are different. Not only does each estuary occupy its own geomorphic and hydrological context, but each has been subject to its own set of land uses.

This variation is best explored through specific examples. The section below introduces a few estuaries that represent common situations (in terms of type, land use and condition). These groups have been selected subjectively to illustrate the range of conditions across Victoria. They do not represent formal or data-derived classes. Many other estuaries fall somewhere between these examples in terms of their scores and land use profiles.

The figures provided for the examples below show some of the spatial data generated by this project. Such data is likely to be more useful than the raw score in many cases, because it shows spatially where condition has been lost or retained. This helps to highlight management issues and intact 'hotspots' which may be priorities for protection.

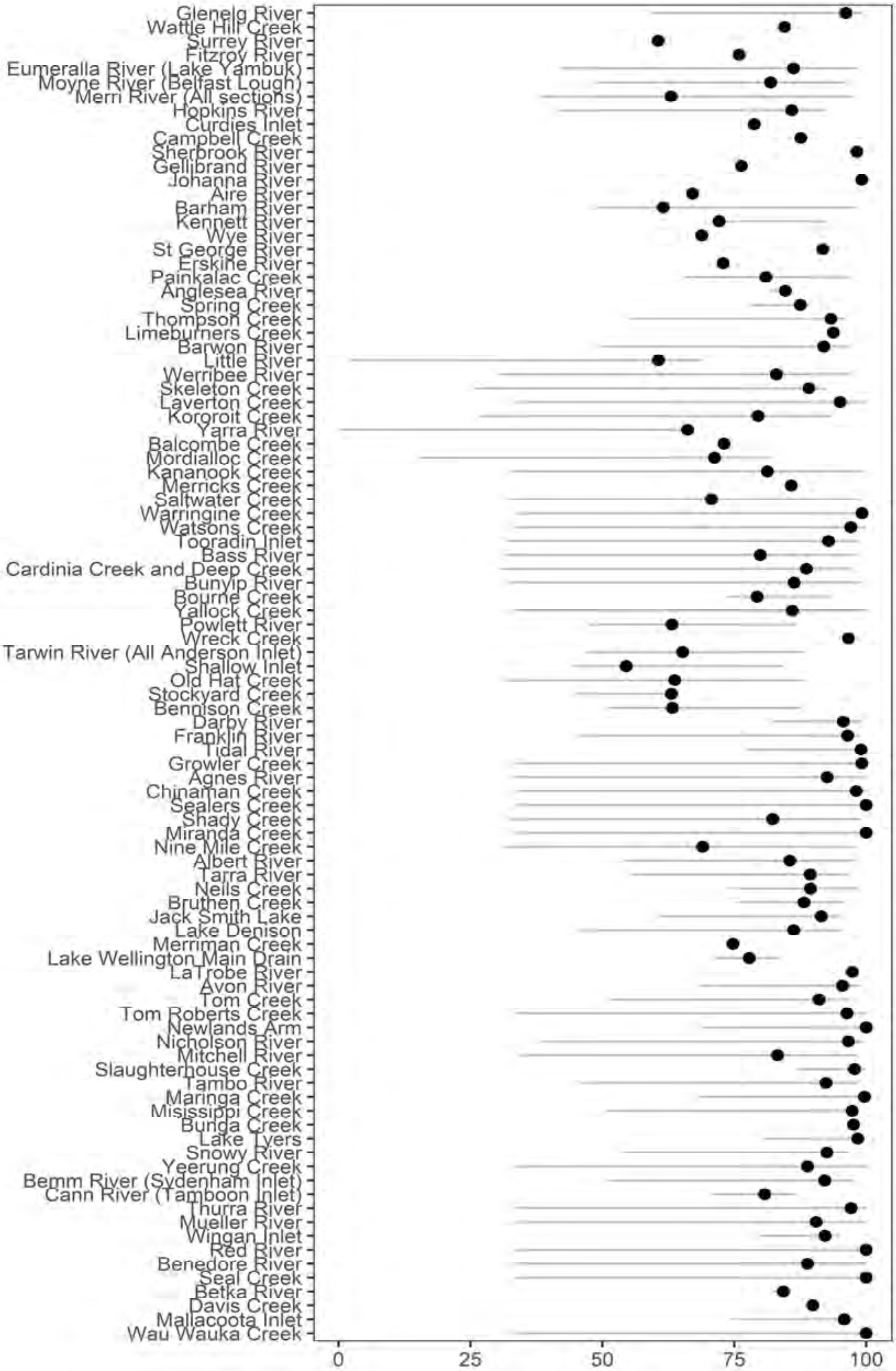

Figure 2. Fringing vegetation scores for Victorian estuaries.

The estuaries are listed west to east. The final score (aggregating the three indicators) is shown (point), along with the uncertainty attributable to imperfect access (dark grey line).

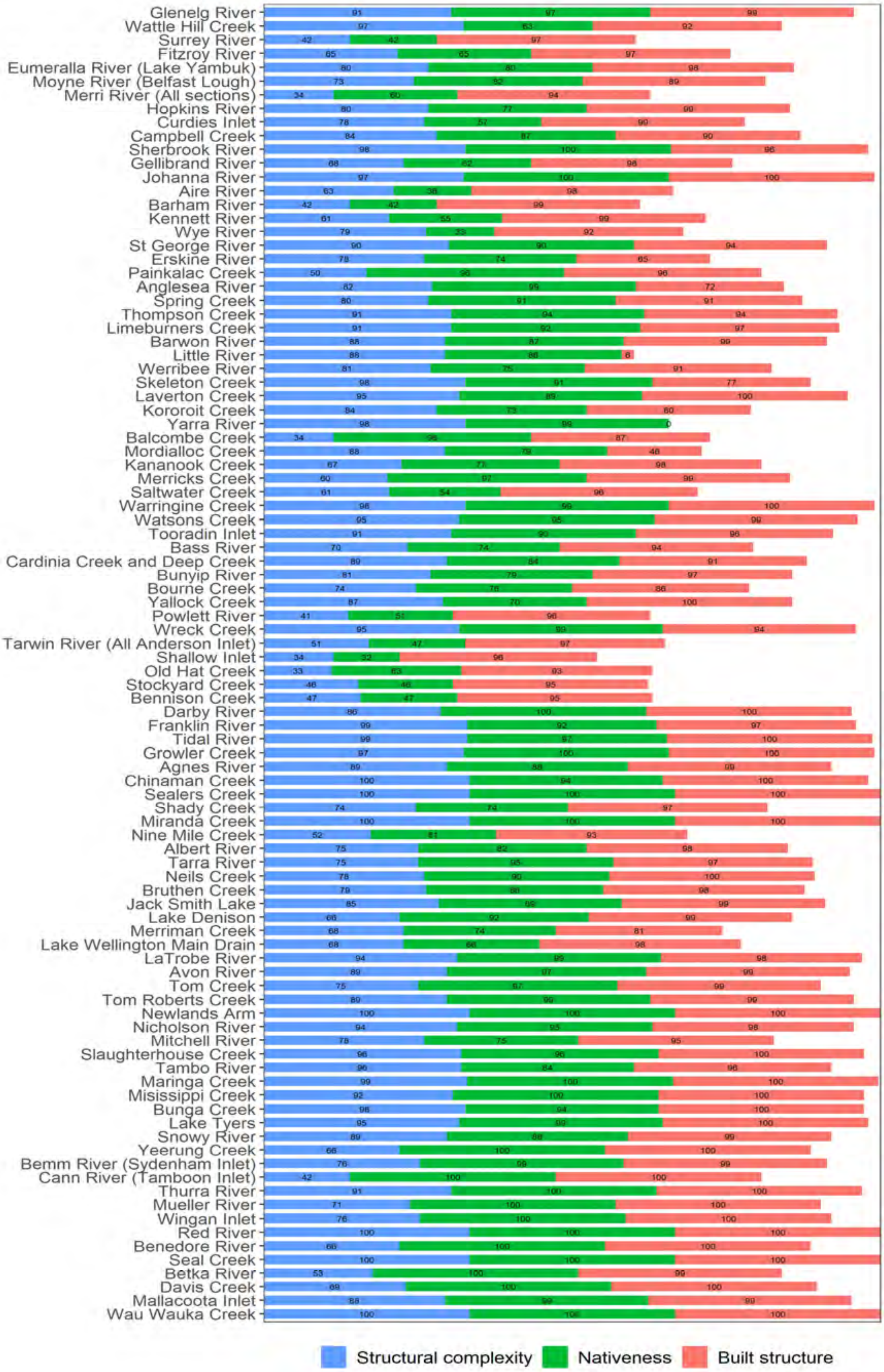

Figure 3. Scores for each of the three fringing vegetation indicators for Victorian estuaries.

The estuaries are listed west to east. Each coloured bar represents the score (out of 100) for each of the three indicators that are combined to produce the final score.

3.1.2 Examples of estuaries in different condition states

Small near-pristine estuaries

Some estuaries have not experienced agricultural or urban development because they occur in remote, inaccessible, unproductive or protected catchments, and are small enough to lack extensive floodplains which would otherwise attract agricultural land use. These estuaries generally have small fringes characterised by vegetation that typically grows on brackish streambanks and small flats, such as Estuarine Wetland (dominate by *Juncus kraussii*) and Estuarine Scrub (Dominated by *Melaleuca* species).

The final scores for these estuaries are high, reflecting negligible impacts from built structures, very low levels of weed invasion, and low levels of physical disturbance and grazing.

The lowest indicator score is generally the structure score. This is due to a single phenomenon: many of these systems are periodically closed by sand bars, leading to flooding that may kill off stands of *Melaleuca*, which go through cycles of death and recolonization. Vegetation which had a dead or depleted *Melaleuca* canopy was scored against the Estuarine Scrub benchmark, and often incurred a score penalty due to a lack of canopy. It is unclear to what extent these dynamics are natural and long-standing, or driven by more recent anthropogenic factors such as reduced rainfall due to climate change. Examples of such estuaries occur in East Gippsland (Thurra River, Mueller River, Wingan Inlet, Easby Creek, Red River, Benedore River, Seal Creek, Betka River, David Creek, and Wau Wauka Creek) and on Wilsons Promontory (Darby River, Growler Creek, Tidal River, Miranda Creek, Sealers Creek). Figures 4 – 6 show the Betka River as an example of these estuaries.

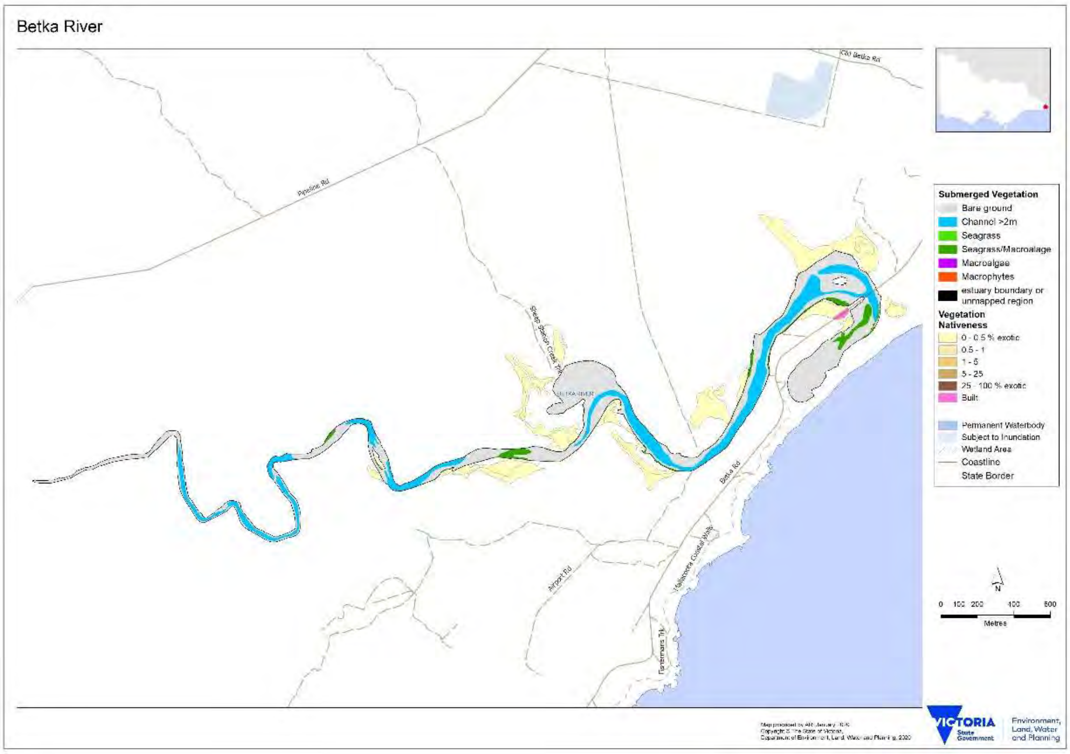

Figure 4. Fringing vegetation data for the Betka River.

This estuary is an example of a small near-pristine system, from the perspective of the fringing vegetation. Note that the fringing vegetation (in yellow) is uninterrupted by built structures, and barely invaded by weeds. For clarity, only the data for Indicators 1 and 2 are shown on this figure. This figure also shows the submerged vegetation.

Figure 5. Fringing vegetation on the Betka River.

This image shows the fringe of Estuarine Wetland (*Juncus kraussii* and *Phragmites australis*) and Estuarine Scrub (Swamp paperbark *Melaleuca ericifolia*). The intact nature of the catchment is evident from the surrounding Eucalypt forest.

Figure 6. Estuarine Scrub dieback on the Betka River.

This image shows the dead stems of Swamp Paperbark (*Melaleuca ericifolia*), which have been killed by flooding due to mouth closure.

Estuaries with extensive fringes degraded by agriculture

Larger estuaries with fringes and catchments that are fertile, well-watered, flat and accessible have generally been impacted by agriculture. These impacts include hydrological modifications from channels and earthern bund walls, removal of vegetation by grazing and the replacement of native species with exotic pasture species. The main vegetation impacted in these areas has been the EVCs Estuarine Scrub, Estuarine Flats Grassland and Estuarine Wetland. Despite these impacts, most estuaries of this kind retain a portion of more intact fringing vegetation on the seaward side of the bund wall. The vegetation retained on the seaward side is largely the EVCs Mangrove Shrubland, Wet Saltmarsh Shurbland and Wet Saltmarsh Herbland.

The condition scores for these estuaries are generally low to moderate, reflecting the high levels of weed invasion, high levels of structural modification, and some modest impacts by built structures (bund walls and channels). The scores vary greatly depending on the position of the lower bund walls, with some estuaries retaining extensive intact seaward areas, and others retaining almost none. In some such estuaries, pasture abandonment has led to some recolonization how much of the fringe remains.

Examples of such estuaries include the Tarwin River (Andersons Inlet), The Aire River, Shallow Inlet, Barham River and many of the moderately-large estuaries around Corner Inlet (Stockyard Creek, Bennison River, Old Hat Creek, etc.). Figures 7 – 9 show the Tarwin River as an example of these estuaries.

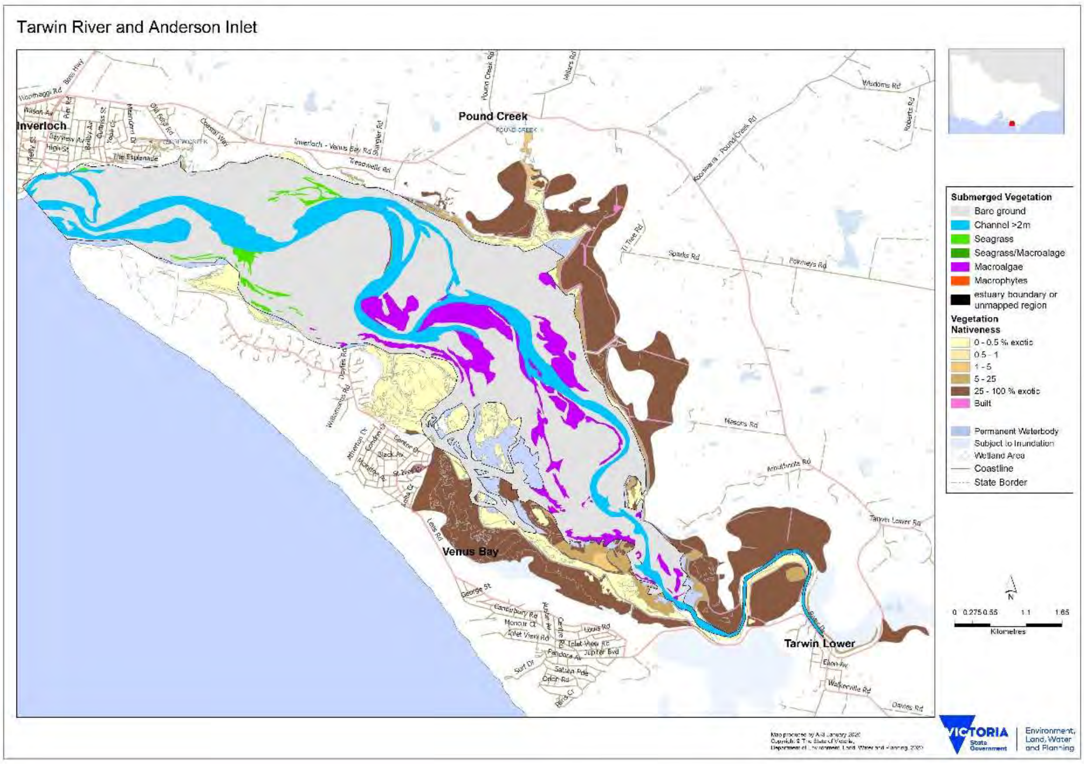

Figure 7. Fringing vegetation data for the Tarwin River (Anderson Inlet).

This estuary is an example of a large system with agricultural impacts. Note that the fringing vegetation landward ot the bund walls is highly weed invaded (in brown), while the vegetation seaward of the bund walls in more intact (yellow). For clarity, only the data for Indicators 1 and 2 are shown on this figure. This figure also shows the submerged vegetation.

Figure 8. Fringing vegetation on the Tarwin River (Anderson Inlet).

This image shows typical vegetation landward of the bund wall, which is partly exotic, but retains some vestiges of the original estuarine fringing vegetation (Here Sea Rush *Juncus kraussii* and Australian Salt-grass *Distichlis distichophylla*). This area once supported a mixture of Estuarine Wetland and Estuarine Scrub. The photograph was taken from the main bund wall.

Figure 9. Fringing vegetation on the Tarwin River (Anderson Inlet).

This image shows typical vegetation seaward of the bund wall, which remains intact (Here Grey Mangrove *Avicennia marina* and Shiny Swamp Mat *Selliera radicans*.

Estuaries with extensive intact fringes

In only a very small number of cases, estuaries with large areas of fringing vegetation have escaped severe and extensive degradation from agricultural land use, and retain intact vegetation across the full ecological amplitude of their fringes. The exemplary cases are the Barwon Estuary, Jack Smith Lake and Mallacoota Inlet. Some slightly smaller and/or more degraded examples include the Snowy River, the Glenelg River and several of the larger estuaries on the Gippsland Lakes. These few systems all retain large areas of estuarine fringing vegetation in good condition with examples of many different EVCs. They dwarf all the other estuaries combined in term of the combined quantity, quality and diversity of their fringing vegetation.

There are several reasons why these systems have escaped degradation: in the case of the Barwon River and Jack Smith Lake it is a combination of hypersaline soils and low rainfall making the areas relatively unattractive for agriculture, in the case of Mallacoota Inlet it is the probably due to the remoteness of the location from other settlement. Figures 10 and 11 show the data and an example of the vegetation for Jack Smith Lake.

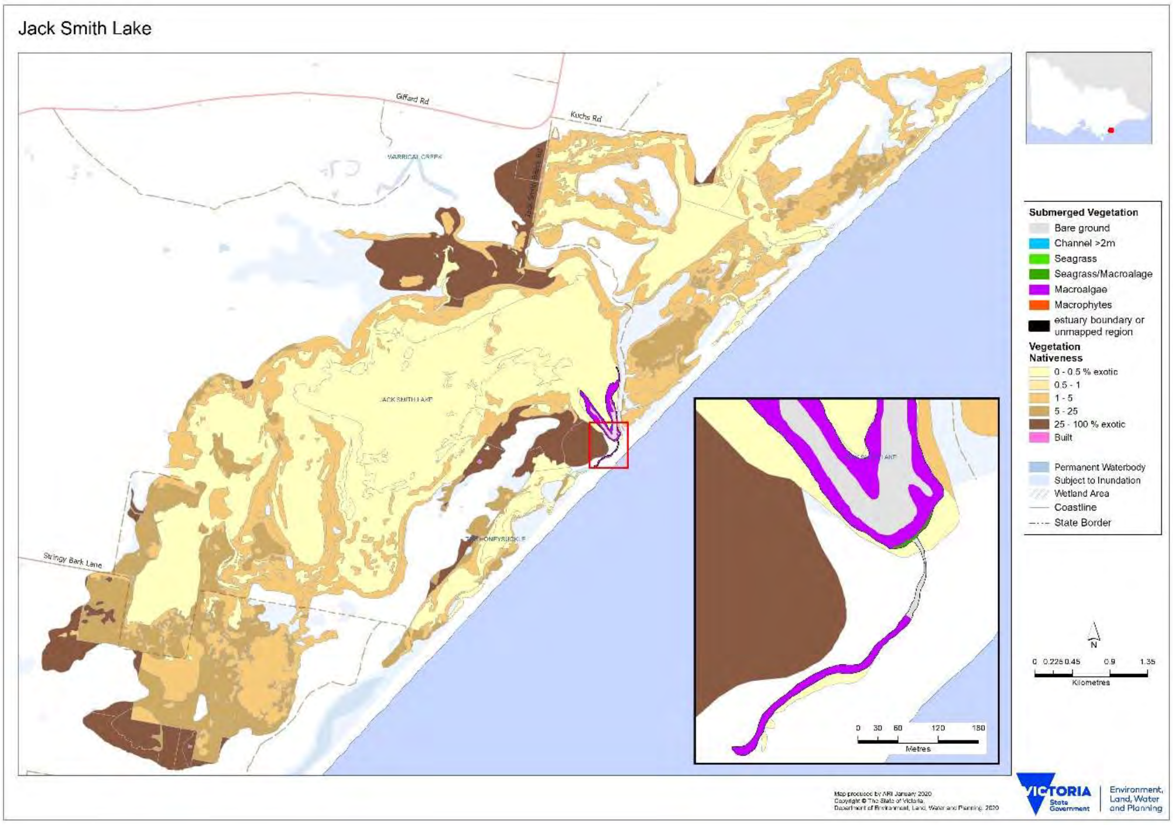

Figure 10. Fringing vegetation data for Jack Smith Lake.

This estuary is an example of a large system with extensive areas of relatively intact fringing vegetation. Note the extensive areas of vegetation with low levels of weed invasion (yellow). For clarity, only the data for Indicators 1 and 2 are shown on this figure. This figure also shows the submerged vegetation.

Figure 11. Fringing vegetation around Jack Smith Lake.

This image shows an extensive area of Estuarine Flats Grassland and Brackish Grassland (Foreground) Dominated by Tussock Grasses (*Poa labillardierei* and/or *Poa poiformis*), and in the background a patch of Estuarine Scrub (with Swamp Paperbark *Melaleuca ericifolia*). There is no comparable area of estuarine grassland remaining in Victoria.

Estuaries degraded by intensive development

Many towns are located on estuaries, since estuaries make natural points for landing, sheltering, transporting and unloading goods. For these estuaries, development has usually resulted in the loss of much of the fringing vegetation under built structures. The areas of remnant fringing vegetation which remain are often physically damaged and invaded by weeds. These estuaries are characterised by relatively low scores.

Examples include the Yarra River, which once had a large estuarine fringe, but which is now almost completely covered by bult structures; and several very small estuaries that flow through coastal towns (e.g. Wye River, Erskine River). Figures 12 and 13 show examples of such estuaries.

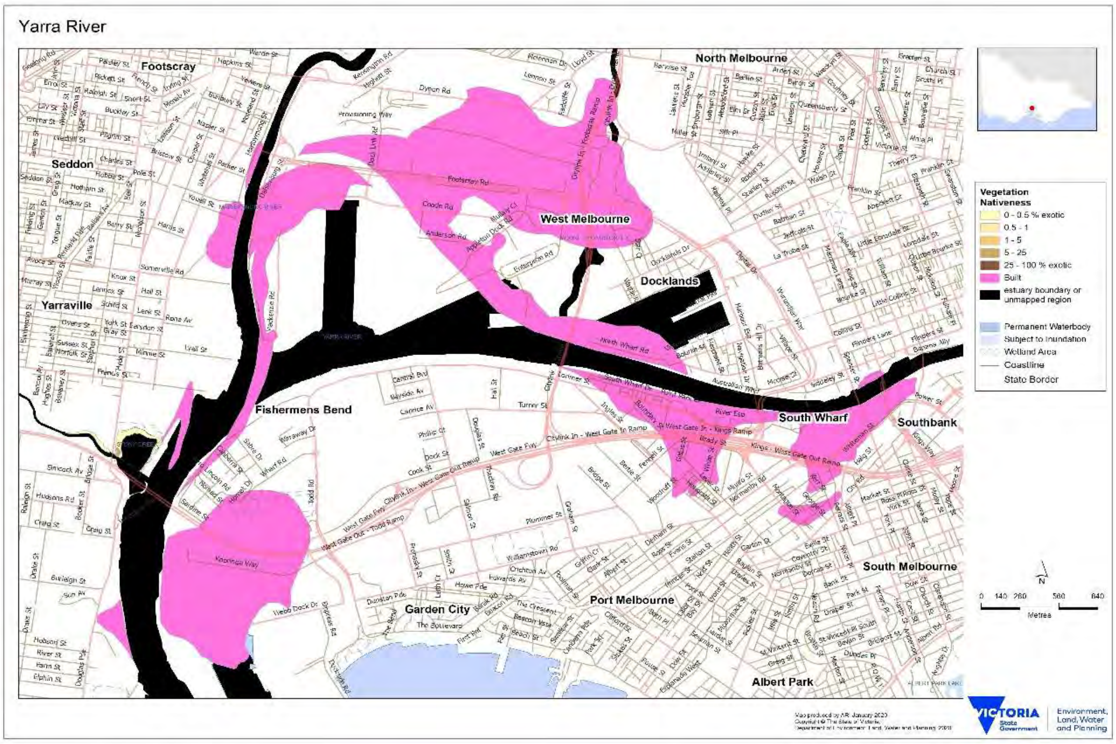

Figure 12. Fringing vegetation data for the Yarra River.

This estuary is an example of a once-extensive system which has been covered by built structures (i.e. the city of Melbourne). For clarity, only the data for Indicators 1 and 2 are shown on this figure. This figure also shows the submerged vegetation.

Figure 13. Fringing vegetation data for the Erskine River.

The Erskine is an example of a small estuary flowing through a coastal town (Lorne). The estuary has been encroached on by built structures (in Pink) and weeds have invaded some of the remining native vegetation (in orange and brown). For clarity, only the data for Indicators 1 and 2 are shown on this figure. This figure also shows the submerged vegetation.

4 Discussion

4.1 Utility

The data presented here can further our understanding of estuaries and our ability to manage them. The primary purpose of the data is to underpin long-term and broad scale monitoring and reporting of estuarine condition across Victoria. Over subsequent decades, managers, decision-makers and the public will be able to see how Victoria's estuaries are tracking, and where intervention is required.

From a more immediate practical viewpoint, the data provide managers and decision makers with detailed information on where degradation has occurred and where values have been retained; across the state, and within each estuary. We hope that the data can be used to prioritise and direct funding to where management is most required. For example, the maps which show weed invasion could be used to prioritise control; and the data that record structural degradation could be used to direct planting.

The data may also assist managers more directly with decisions. For example, many managers must decide whether and when to allow estuaries to be artificially opened to relieve flooding (Becker et al. 2009; Barton and Sherwood 2004). This decision must be informed by the relative risks and benefits to a range of assets, including roads, buildings, agricultural land, fish, birds, water quality and fringing vegetation (Arundel 2006). The map data provided here allow detailed quantification of which vegetation types will be inundated by certain flood levels, and the current condition of those patches of vegetation. This may allow more detailed assessment of flood risk than current approaches (Arundel 2006).

The data may also help elucidate estuarine ecology more broadly, if used alongside data that describe other ecological aspects of estuaries. For example, our detailed data on vegetation types and structural complexity may be useful in exploring how animals interact with different estuaries.

4.2 Limitations

4.2.1 The scope of the metric

As noted in the Introduction, condition metrics are always subjective, and each metric has a built-in point of view. This metric is no exception. This means that metrics do not cover everything, and there will always be some variables that are not captured, or are represented at low resolution. Given this, it must be remembered that the metrics used here do not capture everything that is important, and further observation will often be necessary to understand the ecology of the estuarine fringe.

4.2.2 Estimates and quantitative sampling, broad and narrow scales

Due to the large number of estuaries to be assessed and the practical and financial limitations of field work, we used visual estimates of cover for all assessments. Visual estimates are relatively rapid and therefore cheap, but not optimal for providing data because they are not strictly repeatable and often vary between observers (Vittoz and Guissan 2007). The choice to use visual estimates therefore limits the ability to confidently detect subtle change, which reduces the ability to use our data for fine-scale monitoring.

The metrics outlined here do not need to use estimated data. The data used to calculate the metrics could just as easily come from a quantitative sampling method such as a line-intercept plot (Godínez-Alvarez et al. 2009). Although quantitative methods produce more reliable data, they also introduce problems associated with sampling: whereas visual estimates can easily be applied to any defined area (EVC polygon), sampling quantitatively from many differently shaped and sized polygons requires a detailed and intensive sampling strategy.

We suggest that for the state-wide reporting of estuarine condition visual estimates such as those used here are suitable and appropriate. In contrast, if subtle changes within any given estuary need to be monitored, we recommend a different strategy. In that case, quantitative sampling that targets the variables of interest, and samples on a scale appropriate to the estuary, should be used. In such cases, the primary vegetation data are likely to be useful for understanding changes and drawing inferences, rather than the metric, which should be treated as a secondary means of simplifying and making sense of the primary data.

4.2.3 The influence of the flow-based buffer on the score

Fifteen of Victoria's estuaries have no obvious edge to their fringing vegetation, and merge into the nearby coastal marsh vegetation. For these estuaries, an arbitrary buffer defines the extent of their fringe, which is scaled according to the stream flow, on the assumption that higher-flow streams will exert a wider influence.

The size of this arbitrary buffer impacts the score because the area of the fringe is used as a denominator in the score calculations for all components. This is not a problem for longitudinal comparisons of an individual estuary, but it does mean that the score comparison of one estuary to another is dependent on the arbitrary choice of buffer size.

This effect is exemplified by the comparison between the Franklin River and Stockyard Creek, which both required buffers to delineate their fringes. These estuaries are in a very similar context (low energy coastline in Corner Inlet), and support similar vegetation (mangroves, saltmarsh) with similar surrounding land-uses (earthen bund walls protecting cattle pasture). Despite this, their scores differ (Franklin River scored 96 and Stockyard Creek scored 59). This is largely because the bund walls on Stockyard Creek are close to the channel, with only a narrow strip of remnant estuary vegetation between them, and extensive areas of reclaimed pasture on the landward side. The bund walls on the Franklin River are further from the channel. Given that more of the fringing vegetation on Stockyard Creek has been replaced with pasture, it would be expected that Indicator 2 (nativeness) and 3 (structure) would score lower than those components on the Franklin River. This was indeed the case (See Figure 3). However, the degree to which the scores differ depends on the size of the buffer: A larger buffer would include more pasture in each case, and a larger buffer would mean that the scores for these estuaries would be more similar.

4.2.4 The impact of the 2019-2020 fires

Extensive wild fires burnt most of East Gippsland in 2019-2020, after the field work for this project was complete. All of the estuaries from Wau Wauka Creek in the far east to Yeerung Creek west of Cape Conran (14 estuaries in total) fall within the footprint of the fires. Early aerial reconnaissance confirmed that at least some of the estuarine scrub vegetation was burnt in some of these estuaries, but the full extent of the impact is unknown at the time of publication.

It is worthwhile speculating on the impact these fires may have on the condition of these estuaries. Burnt estuaries will experience losses of condition, and this will be reflected in their scores. Indicator 1 (Built Structures) will be unaffected, Indicator 2 (Nativeness) is likely to be minimally affected (Fires in remote estuarine areas are unlikely to cause substantial weed invasion), while the score for indicator 3 (Structural complexity) is likely to be substantially lowered, given that the cover of most species will be removed.

Recovery of pre-fire condition scores for estuarine systems in east Gippsland is likely to be complete and relatively rapid. This prediction is based on the fact that all of the dominant species reproduce clonally, and are capable of resprouting rapidly after the removal of their foliage (e.g. Swamp Paperbark *Melaleuca ericifolia*, Sea Rush *Juncus kraussii*, Common Reed *Phragmites australis*). While there may be a few species that are adversely impacted, these species are unlikely to occur at high cover, and so do not contribute substantially to the scoring system here (which is cover-weighted).

4.2.5 The uncertainty caused by limited survey access

The scores for some estuaries are presented here with very high degrees of uncertainty, sometimes spanning more than 50% of the score range (See Figure 2). While this clearly limits the resolution of our understanding of estuary condition, it was an expected feature of this study, which was considered against the costs of assessment. As shown in the Results section, the degree of uncertainty does not prohibit useful conclusions being drawn.

4.3 Conclusion

The data from this project provide a comprehensive overview of the condition of estuary fringing vegetation across Victoria in 2017-2019. It is hoped that this data will help us understand change in Victoria's estuaries over decades to come, and help us better manage these important environments under the challenges they will inevitably face from human use, climate change and invasive species.

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Appendix A Definitions

Accurate assessment rests on a number of concepts which require precise definition. This section provides the relevant definitions in alphabetical order. These are taken from Sinclair and Kohout (2018), with minor additions and modifications, where necessary to reflect the way these definitions were applied here.

Benchmarks

A benchmark describes the desired state for a given ecosystem (here Ecological Vegetation Class; EVC). Every EVC encountered on the Estuarine Floodplain is served by a benchmark developed for the Index of Wetland Condition (DELWP 2016b). These benchmarks outline the species composition and structure, according to plant lifeform groups, that would be expected in a site in the desired condition state. Benchmarks are necessary for assessing Indicator 3 (see below), where the lifeform list and threshold cover values listed under "Critical Lifeform Groups" are used.

Built structures

Built structures include anything made from concrete, wood, brick, or formed earth, large enough to be captured at the resolution of mapping. They also include permanent open water in artificial impoundments. They include the following:

- All 'hardened or armoured shorelines' as defined in the IEC Lateral Connectivity component.
- Sea walls and bund walls (wooden, concrete, earthen).
- Substantial roads and tracks (concrete, bitumen, gravel).
- Buildings and carparks.
- Boat ramps (concrete, bitumen, gravel, wood)
- Jetties and piers
- Infill (soil, mud, concrete, gravel), where the height of the land has been artificially raised by the introduction of the material
- Excavations where the original surface has been removed, such as channels
- Artificial permanent water bodies, including treatment ponds at the Western Treatment Plant.

Areas of land that are not 'built structures' may be composed of:

- vegetation (native or non-native; planted or spontaneous)
- bare mud, sand or shell grit
- disturbed ground, including foot tracks and wheel tracks that are not part of a substantial road.

Areas of land behind seawalls (and thus often hydrologically alienated) are considered built structures only if their soil surface has been altered by excavation or infill, or they hold permanent water.

Elevated bridges (e.g. roads over estuaries) are considered built structures when they cross the fringe, regardless of what is underneath them. When they cross the permanently inundated portion of the estuary, they are no longer relevant to the assessment of fringing vegetation, and can be ignored.

Cover

Cover is a quantitative measure of the abundance of plants. It measures the portion of the ground that would be in shade if a vertical light source was applied to an area, and only the target group (species, lifeform, etc.) cast shade. All parts of the plant are included in measures or estimates of cover (leaves, branches, etc.), but any spaces or holes are excluded. No overlaps (i.e. double shading) are recorded within a group. When multiple groups are considered, cover may overlap between groups, such that multiple cover values at a site may sum to > 100% over several groups. Cover here refers to an absolute amount, expressed as a percentage, not any of the commonly used categorical scales (e.g. Braun-Blanquet, etc). It may be estimated visually, or measured using a variety of quantitative means.

Ecological Vegetation Classes (EVCs)

In Victoria, patterns of different vegetation types are classified or mapped using Ecological Vegetation Classes (EVCs). These are descriptive units that may include several floristically distinct vegetation types, unified by analogous environmental conditions and a similar overall structure.

Estuary

This report uses the definition of estuaries used for the IEC more generally: estuaries are partially enclosed waterbodies that may be permanently or periodically open to the sea and, because of the dilution of ocean water with fresh water, have salinities that vary from almost fresh to very saline (Tagliapietra et al. 2009). Estuaries are included for assessment if they are at least 1 km long, or have lagoonal lengths of at least 300 m. Watercourses that run into coastal embayments (Western Port, Port Phillip Bay, Corner Inlet) or into the Gippsland Lakes are included, if they fulfil the length criterion (Pope et al. 2015).

In Victoria, the Gippsland Lakes system could be considered an estuary in itself (it experiences a salinity gradient across its length). However, here the view is taken that the rivers which empty into the Gippsland Lakes each end in a distinct estuary (i.e. it is assumed that the lakes system are a coastal embayment, or part of the ocean). This view is in line with the other elements of IEC. While strictly out of step with the definition of an estuary, it is taken for pragmatic reasons, It allows each smaller drainage system to be treated separately, and prevents the massive and complex lakes system being treated as one entity, thus allowing finer-resolution reporting.

Exotic and native species

Exotic species are those which are listed as “naturalised”, “incipiently naturalised” or of “uncertain origin” by the Royal Botanic Gardens Victoria (Walsh and Stajsic 2007, including any updates published online at https://vicflora.rbg.vic.gov.au), plus any non-native species newly detected in Victoria but not yet on those lists. No distinction is made between planted or naturally-occurring individuals of native or exotic species.

Fringe

The area occupied or formerly occupied by fringing vegetation (see below). This is the area of assessment for the fringing vegetation component of IEC. It includes unvegetated areas of mud, sand and shell grit within the extent of the fringing vegetation. It also includes all built structures or excavations which occur within the area formerly occupied by fringing vegetation.

Fringing vegetation

Fringing vegetation is that vegetation above the permanently inundated portion of the estuary, which naturally experiences some hydrological influence from the salty waters of the estuary (aided by the use of salt-indicating plant species, see below). This vegetation may be inundated or waterlogged periodically by seawater flowing into the estuary and/or water from the catchment.

Fringing vegetation excludes all built structures (defined above). Delineation of the fringing vegetation may be difficult in practice. This issue is discussed in detail below (Delineation of the fringing vegetation).

To avoid inconsistency in application, the extent of fringing vegetation has been defined for each estuary during this first assessment, and will remain unchanged for future assessment, unless the estuary expands (see below, Delineation of the fringing vegetation; Treatment of estuaries that have shifted location).

Lifeforms

‘Lifeforms’ are categories that group plants together, with plants in a group sharing very similar forms (e.g. shrubs as opposed to trees, rhizomatous grasses as opposed to tussock grasses), sizes and life histories (e.g. annual as opposed to perennial). The life-form groupings to be used here will be those already defined for habitat hectares and IWC. Which set is relevant will depend on which benchmark is used for a given EVC. No new lifeform classes are defined for IEC.

Native vegetation

‘Native vegetation’ is defined according to DEPI (2013, p5.):“…either…an area of vegetation where at least 25 per cent of the total perennial understorey plant cover is native, or any area with three or more canopy trees where the canopy foliage cover is at least 20 per cent of the area. In Victoria, all vegetation can be described by an Ecological Vegetation Class (EVC).

Patch

A patch of vegetation includes any area that is of a single EVC, and is assignable to a single condition state (i.e. a habitat zone as defined in habitat hectares, Parkes et al. 2003). It is the basic unit of a condition assessment. If an assessor judges that some vegetation in a given EVC is substantially more or less degraded than others, such different areas should be divided into different patches. If an assessor judges that all vegetation in a given EVC is in the same condition class, a single patch is defined, and a single assessment is made. A patch may be made up of multiple, disconnected polygons.

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