Assessment of fringing vegetation for the index of estuary condition

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Front cover photo: Vegetation fringing a small tidal creek at low tide, Western Port (Steve Sinclair).

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Context:

The Victorian Index of Estuary Condition (IEC) has been developed by the Victorian Government to improve estuary management, by providing a means of assessing and scoring estuary condition. 'Condition' is a concept with multiple components. Reflecting this, multiple components of estuarine condition have been identified, including the vegetation that fringes the estuary on its inland margin. No detailed protocol for assessing the 'fringing vegetation' has previously existed.

Aims:

This project aimed to provide a rationale and a method for assessing the condition of estuarine fringing vegetation, to be incorporated into the IEC.

Methods:

In order to be consistent with the other components of IEC, and with Habitat Hectares, IWC and ISC, we determined at the outset that the metric would consist of several independent indicators, and that these would be scored separately and combined via addition (or equivalent). Noting that condition is subjective, we based the metric on consultation with a small but knowledgeable group of experts. We selected three indicators for the metric. We also trialled the metric in a pilot study by applying it to six Victorian estuaries, with varied characteristics (Anglesea River, Thompson Creek, Barwon River, Tarwin River, Stockyard Creek, Franklin River).

Results:

The recommended method of assessment uses three distinct indicators, each of which is scored on a 0–100 scale:

- Percentage of fringe that is covered by built structures. This indicator assesses the percentage (0 – 100%) of the estuary's fringe composed of built structures. Built structures 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.
- 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, an abundance of weeds confers a low score.
- Structural complexity of the fringing vegetation. This indicator compares the vegetation under assessment to a vegetation-type specific benchmark, which specifies the cover of plants expected within each lifeform category. The observed vegetation is scored down if the expected lifeforms are absent or display insufficient cover.

The scores derived for these indicators are averaged (arithmetic mean), to produce a score out of 100.

The fringing vegetation assessment also records ecological observations that do not contribute to the score, including the health of plants and the degree of physical damage to the vegetation.

The pilot study showed that the method was practical to implement.

Conclusions:

We recommend that the method developed here be incorporated into the IEC. The method is considered suitable for:

- contributing to the periodic condition reporting of all estuaries in Victoria
- providing information to assist in the prioritisation of management investment between estuaries, and
- informing a baseline for assessing long-term and large-magnitude changes in resource condition.

1 Introduction

1.1 Background and purpose

Estuaries occur where freshwaters meet the sea, usually at the mouths of rivers. More precisely, they 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). Through them, many organisms, nutrients and pollutants may move between inland rivers and the open ocean.

The Victorian Index of Estuary Condition (IEC) has been developed by the Victorian Government to improve estuary management (Annett and Adamson 2008). It aims to assess estuarine condition for the purposes of:

- Reporting periodically on the condition of estuaries in Victoria;
- Assisting prioritisation of management investment among estuaries;
- Providing a baseline for assessing long-term and large-magnitude changes in resource condition.

These goals are to be accomplished by measuring a series of field-based indicators at estuaries across Victoria, and using these measurements to derive a condition score for each estuary. A suite of recommended indicators, a sampling protocol, a tiered monitoring scheme, and approaches for refinement have been developed, trialled and appraised (Warry and Reich 2013, Pope et al. 2015; Woodland and Cook 2015).

Five themes have been identified for assessing estuarine condition: physical form, hydrology, water quality, flora and fauna (Arundel et al. 2009, Woodland and Cook 2015). Apart from the fringing vegetation component of the flora theme, each is served by a set of indicators and an assessment method. This document provides a rationale and a recommended method for assessing the condition of estuarine fringing vegetation (hereafter referred to as the metric) to be incorporated into the IEC.

Fringing vegetation is recognised as essential to the ecological structure and function of estuaries (Arundel et al. 2009, Victorian Saltmarsh Study 2011, Pope et al. 2015). The degradation or loss of fringing vegetation impacts estuarine biological function (Roper et al. 2011).

1.2 The evaluation of ecological condition

1.2.1 What is ecological 'condition'?

Despite its importance and intuitive meaning, there is no universally-accepted conception or definition of 'ecological condition', neither in the global ecological literature nor the Victorian policy context (Oliver et al. 2002, Parkes and Lyon 2006, Gibbons and Freudenberger 2006, Stoddard et al. 2006, Sinclair et al. 2018). Given this, each effort to assess ecological condition must select or formulate a definition. The following definition, taken and modified from The Victorian Saltmarsh Study (2011), is considered suitable here, since it was developed for intertidal wetland systems and is consistent with all relevant Victorian policies and tools – such as Habitat Hectares (Parkes et al. 2003), Index of Wetland Condition (IWC, DSE 2005a, 2009, DELWP 2016a, 2016b) and Index of Stream Condition (ISC, DSE 2005b).

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

The 'desired state'is generally (but not always) 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 structures and networks, given the systemic constraints on primary production.
- It is able to support maximum diversity of native species (excluding ruderals and generalists), given the systemic constraints on 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.

1.2.2 Dealing with subjectivity

Evaluating ecological condition is inherently subjective (Daniel and Vining 1983, Keith and Gorrod 2006, Sinclair et al. 2015, 2018). This is evident in the selection of which elements of the ecosystem to score (e.g. fish abundance? Sea-grass cover?), how each element is related to condition (how much sea grass cover is best?) and how much weight is given to each element in an overall evaluation (Buckland et al. 2005).

This poses a problem: Why is an evaluation credible, if it is merely an opinion? This can be addressed in two ways. The first is by consultation to develop a collective opinion, which gains credibility from its democratic origins (Oliver et al. 2007; although it is often difficult to derive a coherent opinion from consultation; Wood and Lavery 2000; Venables and Boon 2016). The second is to construct a transparent metric that allows evaluations to be made repeatedly using the same criteria, which confers credibility from transparency and consistency (Gibbons and Freudenberger 2006, Sinclair et al. 2018).

These approaches are frequently combined, such that stakeholder consultation leads to a standard set of measures which are combined to produce a score that reflects ‘condition’, in a way that conforms to stakeholders’ views and the scientific literature (Parkes et al. 2003, Geneletti 2005, Sinclair et al. 2015, 2018).

1.2.3 Benchmarks and variation

The combination of measures which describe the desirable state are often used to define a ‘benchmark’ (or ‘reference state’, ‘baseline’) which is used to score other sites, by their degree of deviation from it (see definition of condition, above) (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).

Variation between time and place is inevitable in ecology, even in pristine systems, such that some deviation from any defined ‘desired state’ will represent natural variation that would not normally be considered a loss of condition. This is a problem for scoring; and it is acute for estuaries, which vary greatly, often across a wide range of spatial and temporal scales (see below).

There are two main ways to deal with this variation. The first is to use local benchmarks, where particular sites are compared only to themselves (i.e. longitudinal studies). Local benchmarks deal with diversity, but do not easily allow cross-comparison (McCarthy et al. 2004). Local benchmarks do not distinguish local changes in ‘condition’ (i.e. degradation or improvement) from benign temporal fluctuations, seral or cyclical changes. The second approach is to make allowances in the benchmark, either by having multiple benchmarks, or by ‘setting the bar low’ such that there is sufficient tolerance in the benchmark to allow variation to occur without a penalty.

1.2.4 Distinguishing assets from threats, and phenomena from their indicators

Many complex ecological factors that might contribute to a shared concept of estuarine condition cannot be easily measured in the non-research context of the IEC. Rather than assessing these complex factors directly, many condition metrics opt to assess some parameter that is easier to assess, but which is an indicator of the fundamental process or asset of interest, or a threat or pressure that is thought to act on the process or asset (Niemi and McDonald 2004, Roper et al. 2011, Venables and Boon 2016).

While the distinction between threat, indicator and asset central phenomenon is important, it is not always easy to sort out what is what. In a riverine context, for example, river-bed damage by carp may be seen as a direct loss in condition (if an intact river bed is an asset), or as an indicator of a threatening process (the presence of an invasive species which is a pressure on native assets). Moreover, what is considered a threat from one perspective may be considered a value from another. Seawalls and drainage channels would usually be considered a threat from an ecological perspective, but may justifiably be considered a value with regard to social and economic considerations.

1.2.5 Combining multiple indicators

A complex concept like ‘ecological condition’ is generally agreed to have multiple elements, and thus multiple variables are required for its measurement (Parkes et al. 2003, Sinclair et al. 2015, 2018, Venables and Boon 2016). Whenever multiple parameters are required, the problem of how best to combine them arises (Buckland et al. 2005).

If the parameters are all the same type (e.g. the abundances of multiple species), then they can be combined with a good degree of mathematical rigour (Buckland et al. 2005). It is more difficult if the parameters are of different kinds, as they generally are for ‘ecological condition’. The most common approach is to assess them separately, and then add them together (or average them), sometimes with a weighting which emphasises some variables at the expense of others (Parkes et al. 2003, Geneletti 2005, Reza et al. 2013).

This approach is usually considered adequate, but it is arbitrary, and it generally disallows the explicit treatment of interactions between variables (Sinclair et al. 2015, 2018).

Alternatives to weighted addition are available, but few scoring metrics use them. One is to take the highest score among the indicators, and ignore the others (if the purpose of assessment is to seek outstanding attributes), or to take the lowest (if the purpose is to identify problems). Another is to use decision trees (or similar) to combine the indicators in ways that allow the value of one indicator to determine the way in which another is used (Sinclair et al. 2015, 2018).

In the current context, it was decided *a priori* that multiple indicators will be scored separately and summed. This decision was taken because the overall IEC uses this approach, as do all of its other components (Woodland and Cook 2015). Further, all other condition assessment tools endorsed by the Victorian Government take this approach (Parkes et al. 2003, IWC, DSE 2005a, 2005b).

1.3 Fringing vegetation in Victorian estuaries

'Fringing vegetation' is taken here to encompass the vegetation which grows above the permanently inundated portion of the estuary, but within the zone of influence of the more-or-less saline estuarine waters. It includes intertidal areas and riparian areas in the estuary but not subtidal vegetation (more precise working definitions of vegetation zones are provided below, under 'Definitions').

The IEC metric for assessing fringing vegetation must be sufficiently flexible to deal with the variation within and among estuaries across Victoria. Victorian estuaries are not particularly diverse on a global scale: Victoria possess only a few of the nine types of estuaries which Roy et al. (2001) defined, based on geomorphological and hydrological criteria. The majority of Victoria's estuaries are brackish mouths of rivers and streams that flow directly into the ocean or into large marine bays (such as Port Phillip Bay, Western Port and Corner Inlet). There are more than 100 estuaries in Victoria; 83 of which exceed one kilometre in length.

Despite their relative similarity in a global context, each estuary in Victoria supports fringing vegetation which differs in type and extent from other estuaries, to the extent that a single benchmark cannot encapsulate the natural variation among them. Consequently, distinguishing inherent differences in type from differences in condition is not trivial (Sinclair and Sutter 2008, Osler et al. 2010, Victorian Saltmarsh Study 2011, Boon et al. 2015). This within-Victoria diversity of estuarine habitats is due, in part, to the variation in geomorphology (Roy et al. 2001) and rainfall across the Victorian coast. These factors influence the physical form, hydrology, soil type, water quality and sediment load of estuaries (Pope et al. 2015).

In the regularly inundated intertidal zone, where salt and fresh water combine, salinity and inundation are the strongest influences on vegetation. A relatively small number of plant species able to survive in this zone. Consequently, the vegetation in this zone in virtually all estuaries in Victoria is predominantly characterised by the same relatively small number of plant communities, composed of a relatively small number of species.

In Victoria, five broad plant communities make up the bulk of vegetation in the estuarine fringe:

- Mangroves. This vegetation grows in the intertidal zone, where daily tides inundate mudflats. In Victoria it consists solely of Grey Mangrove (*Avicennia marina* var. *australasica*) (Duke 2006), and occurs eastward from the Barwon estuary.
- Coastal saltmarsh. This vegetation occurs in the intertidal zone under varying inundation regimes. In Victoria it generally consists of low succulent chenopods, sedges and forbs, forming a wide range of floristic associations and structural types (Boon et al. 2015).
- Marshlands. This vegetation occurs in wetland or dampland areas that experience fresh water inputs from seepage or river flows. In Victoria, estuarine marshlands consist of relatively tall emergent grasses and grass-like plants including Sea Rush (*Juncus kraussii*) and Common Reed (*Phragmites australis*).
- Ephemeral pools. These may fill from tidal inundation or rainfall, and dry following evaporation. At different times, they may be filled with fresh, brackish or hypersaline water, and may be almost devoid of vegetation, or filled with submerged plants such as Water Mats, Water Tassels (*Ruppia* and *Lepilaena* spp.) and Charophyte algae.
- Swamp scrub. This vegetation occurs generally on brackish, waterlogged soil, and consists of dense stands of shrubs in the family Myrtaceae (in eastern Victoria Swamp Paperbark (*Melaleuca ericifolia*) is most common, in western Victoria a range of *Melaleuca* and *Leptospermum* species occur (Boon et al. 2016)).

These vegetation types occur singly or together, in large or small quantity, depending on the local characteristics of each estuary. For most estuaries across Victoria, these few vegetation types make up most of the fringing vegetation.

Beyond the regularly inundated intertidal zone, other factors such as topography, soil, aspect and local rainfall may exert a stronger influence on the fringing vegetation, and estuaries may assume very different characters to each other in these outer portions of the fringe.

It is noteworthy that the extent of the fringing vegetation varies greatly between estuaries. Some estuaries of relatively minor streams surrounded by relatively steep terrain have only a small area of fringing vegetation (e.g. Painkalac Creek at Aireys Inlet). Other estuaries are surrounded by hundreds of hectares of fringing vegetation (e.g. the Barwon River at Ocean Grove).

In Victoria, all vegetation types can be described by an Ecological Vegetation Class (EVC). EVCs form the basis of part of the assessment method described below, but it is beyond the scope of this report to describe these in detail. Other resources can be used to define and delineate EVCS (e.g. DSE, 2012, DELWP 2016b, Boon et al. 2015).

1.4 The value of fringing vegetation

Fringing vegetation is a vital consideration in the assessment of estuary condition. This contention is based on the ideas that fringing vegetation has inherent value (it is an asset in itself), and that its condition influences the rest of the estuary.

The inherent values of the fringing vegetation include those organisms which largely inhabit the fringe; some of which may be rare or threatened (e.g. Salt Lawrencia, *Lawrencia spicata*). This inherent value may also include aesthetic values, and provide a basis for tourism, recreation, education, and research (Barbier et al. 2011).

The nature and integrity of the fringing vegetation also influence the rest of the estuary. Flows of water, chemicals (nutrients, toxins) and organisms that come from the catchment are often filtered through fringing vegetation (Mondon et al. 2009). The vegetation of an estuary affects primary and secondary production, and therefore food web structure (Victorian Saltmarsh Study 2011). Fringing vegetation may also input into adjacent systems, by exporting vascular plant detritus into offshore food webs (Victorian Saltmarsh Study 2011). Fringing vegetation provides stormwater control and reduces lateral erosion and littoral water velocity during river flooding (Adams and Riddin 2007). Estuaries naturally protect the quality of coastal waters by diluting, filtering and settling out sediments and excess nutrients (Tagaza 1995), and fringing vegetation is important in this capacity.

The fringe also provides habitat (snags, roots, perches) for many estuarine animals, some of which may be listed as threatened (Saintilan and Rogers 2013). Many fish species that live as adults in the aquatic portion of the estuary or the sea beyond live as larvae in the shallows amongst the vegetation that fringe estuaries (Hindell and Jenkins 2004, Nagelkerken et al. 2008). The quality of larval habitat varies depending on vegetation cover, type, structure and structural complexity, so that the condition of the fringing vegetation is directly related to larval habitat (e.g. Payne and Gillanders 2009).

Many birds also use the fringing vegetation. Small passerines use the dense riparian vegetation for roosting (Victorian Saltmarsh Study 2011, Pope et al. 2015). In Victoria, saltmarshes provide an important food source for the critically endangered Orange-bellied Parrot (*Neophema chrysogaster*) (Mondon et al. 2009). Saltmarshes also provide important habitat for migratory birds and provide nest sites for colonial-nesting waterbird species (Spencer et al. 2009).

1.5 Threats to fringing vegetation

Understanding the pressures and threats to the fringing vegetation of Victorian estuaries can help the development of suitable indicators (Barton 2003). Figure 1 shows the assumed relationships between threats and the structure and function of Victorian estuaries. In line with the other foundational documents for IEC (e.g. Warry and Reich 2013), it breaks down 'threats' into anthropogenic disturbances (i.e. the activity that causes the threat), the stressor (i.e. the element of that activity which impacts negatively on estuarine ecology), the ecological processes that respond, and the measurable change to the fringing vegetation that results. It also shows some of the 'downstream' effects on other parts of the estuary. The threats and linkages in Figure 1 are discussed below.

Since estuaries are at the bottom end of catchments, their condition can be affected by activities occurring within the upstream freshwater catchment. Broadly, threatening processes that may compromise the functioning of estuaries include habitat loss (Sinclair and Boon 2012), habitat modification and fragmentation, eutrophication, toxic pollutants, altered hydrology, introduced plants, grazing and recreation (Barton 2003, Barton et al. 2008, Victorian Saltmarsh Study 2011, Boon et al. 2015). These may stem from land use in the catchment (e.g. fertiliser application, damming of creeks), direct changes to the estuary (e.g. coastal urbanization, estuarine grazing), and the modification of flows from the downstream end (e.g. opening of mouths) (Barton et al. 2008). We note that the threats interact, and that our presentation of them is a simplification of the complex web of threatening processes. The processes included in Figure 1 are described in more detail below.

Figure 1 also shows the aspects of fringing vegetation that each of the potential indicators measures (see below). It thus shows the links between the IEC scoring metric, and the threats and values of estuarine fringing vegetation.

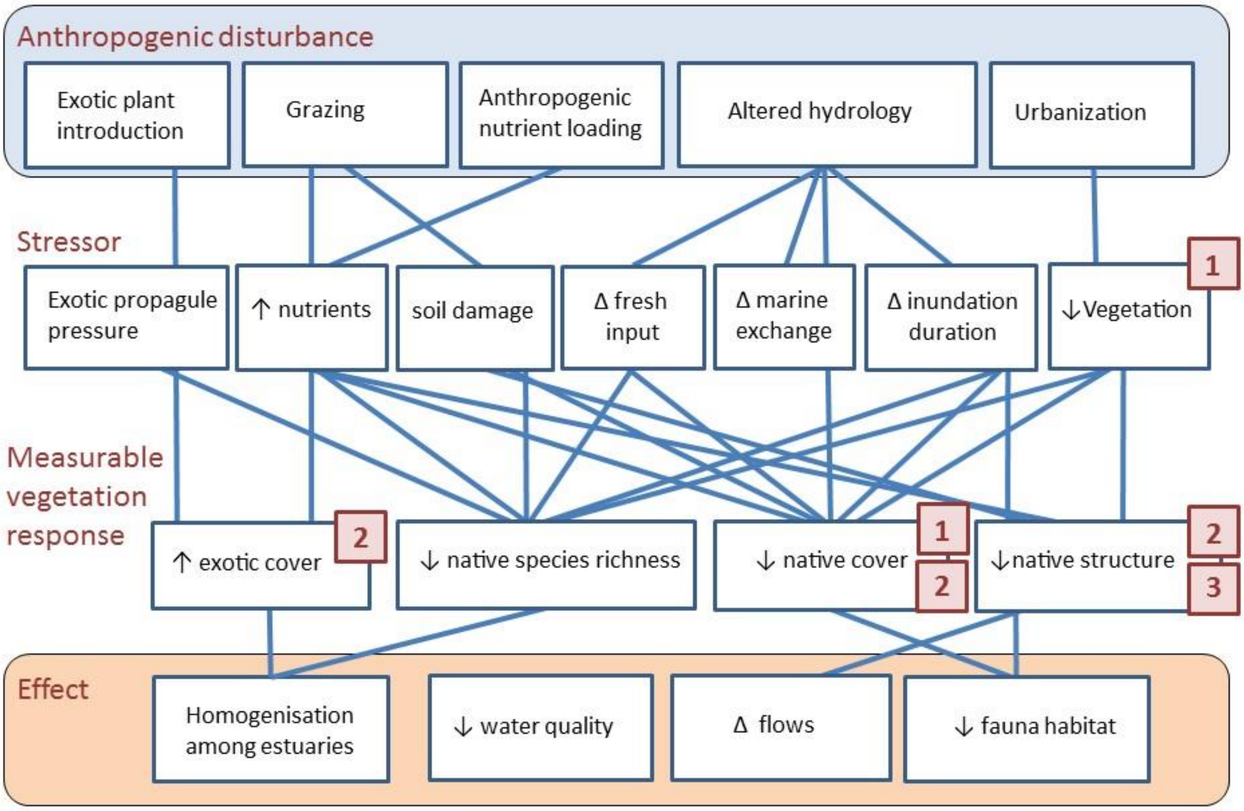

Figure 1. Conceptual model showing disturbances, stressors and effect on estuaries.

The numbered boxes show which elements are addressed by each of the three indicators for measurement: 1. Percentage of fringe that is covered by built structures, 2. Nativeness of the fringing vegetation, 3. Structural complexity of the fringing vegetation.

1.5.1 Exotic plant introductions

In Victorian mangroves and saltmarshes, 47% of plants species are exotic (Victorian Saltmarsh Study 2011). Plant invasions may have consequences for estuary function. Plant invasions have the potential to reduce the diversity of native species through competition. Prominent among exotic plants are the Spartinas or Cordgrasses (*Spartina anglica* and *Spartina* x *townsendii*), which were deliberately introduced to stabilise estuarine foreshores and to protect assets such as port infrastructure. In Victoria, Spartina colonises areas in the mangrove and seagrass habitat (Victorian Saltmarsh Study 2011). The impacts include the competitive replacement of native species, increased sedimentation, impacts on food-web structure, changes in benthic fauna and a loss of foraging areas for birds (Callaway and Josselyn 1992). Hurst and Boon (2016) collated a list of other problematic species, and concentrated on the spread and control of one of the most invasive of the exotic taxa, Wheat Grass (*Lophopyrum ponticum*), which was also introduced intentionally. The rate of and degree of some weed invasions in estuarine systems have been linked to anthropogenic disturbances like eutrophication and removal of native vegetation (see below; Bertness et al. 2002), but disturbance is not necessarily a precursor to invasion.

1.5.2 Grazing

Grazing by livestock can cause immediate damage to estuarine fringing vegetation, via the removal of woody species seedlings and damage to adults (such as Melaleuca and Leptospermum species). It can promote exotic species, and can damage soil structure (Sinclair and Sutter 2008, Victorian Saltmarsh Study 2011). Grazing is also associated with (and may partially cause) eutrophication. In a minority of cases grazing may also have benefits, if it prevents the over-accumulation of biomass, and preserves open spaces which permit native species to live and reproduce.

1.5.3 Anthropogenic nutrient loading

Farming practices routinely involve the application of fertiliser, which often leads to excess nutrients, locally and downstream ('eutrophication'). Eutrophication can affect competitive interactions between plants, rates of herbivory and food web dynamics (Bertness et al. 2002, Victorian Saltmarsh Study 2011).

1.5.4 Altered hydrology

It has been known for decades that hydrology is generally the most important factor controlling the structure and function of the vegetation that fringes estuaries (Clarke and Hannon 1967, 1969, 1970; Boon et al. 2016). Altered hydrology, therefore, can be a potent threat to estuarine fringing vegetation (Arundel et al. 2009). It may result from activities or structures that change the tidal flows of seawater from the ocean (e.g. entrance opening, sea walls, culverts) or the pattern of freshwater flows from the catchment (e.g. dams, culverts, stormwater inputs). Its impacts on the fringing vegetation result from plant species (and therefore communities) having specific requirements and tolerances of inundation length, frequency and salinity levels. Changes to these factors may kill plants, and lead to their replacement by other species.

1.5.5 Urbanisation and direct destruction

Urbanisation and direct destruction of the fringing vegetation is a major threat, and the most immediate. It has the potential to modify the structure and function of estuarine ecosystems and contribute to the decline of biodiversity (Kennish 2002, Barbier et al. 2011). Development pressure around estuaries often results in physical destruction of the fringing vegetation by trampling and/or construction of infrastructure (Arundel et al. 2009, Prahalad 2014), and the loss of fringing vegetation is often a precursor to further adverse impacts on the estuary (Prahalad 2014). Almost all coastal areas in Australia have experienced a degree of habitat modification since European settlement (Victorian Saltmarsh Study 2011). Up to 20% of coastal marsh has been estimated to have been lost across Victoria since European settlement (Sinclair and Boon 2012). In Port Phillip Bay alone, it has been estimated that up to 65% of coastal saltmarsh has been lost through clearing or development (Ghent 2006, Victorian Saltmarsh Study 2011).

1.5.6 Climate change and sea level rise

The anticipated changes in temperature, sea level, carbon dioxide concentration, rainfall and fire regimes are all expected to impact estuarine fringes (Osland et al. 2016). Indeed, over the last few decades, changes attributable to these factors appear to have caused large scale changes to coastal marshlands in Tasmania, including changes in plant species composition consistent with increasing aridity (Prahalad et al. 2011).

The effects may be related to the physiological tolerances of the dominant plants. For example, mangroves are expected to be affected substantially, with direct influences from temperature, sea level and rainfall changes. Low winter temperatures are believed to limit the vigour and geographic distribution of mangroves in Victoria (Ashton 1971). Mangroves occur only in a narrow elevational zone, between mean sea level and mean high tide level (Clarke and Myerscough 1993), and even slight changes in eustatic sea level could alter their distribution locally and regionally (Krauss et al. 2013). Changes in precipitation could also affect mangroves via local salinity changes in sediments and via larger-scale impacts on run-off from the catchment (Heard et al. 2017 a, b).

Beyond the direct physiological effects of sea level, temperature and rainfall, all the relevant vegetation communities are expected to be affected by shifting competitive interactions between species. For example, saltmarsh contains dominant species possessing all three ecologically important photosynthetic pathways (e.g. Beaded Glasswort (*Salicornia quinqueflora*) possesses the C3 pathway, Australian Salt-grass (*Distichlis distichophylla*) possesses the C4 and Rounded Noon-flower (*Disphyma crassifolium* subsp. *clavellatum*) the CAM pathway; Victorian Saltmarsh Study 2011). Changes in carbon dioxide concentration, temperature and moisture availability will thus cause these species to gain or lose their competitive abilities in comparison to the species around them. This is expected to cause changes in species composition and habitat structure (Victorian Saltmarsh Study 2011).

2 Development of the fringing vegetation assessment

2.1 Overview of approach

To be consistent with the other components of IEC, and with Habitat Hectares, IWC and ISC, we determined a priori that the metric would consist of several independent indicators, and that these would be scored and combined via addition. Noting that condition is subjective, we sought to consult a small but knowledgeable group of experts, and then construct a repeatable metric.

2.2 Consultation to define the indicators

We consulted five ecological experts, with direct experience with estuarine fringing vegetation. These experts were affiliated as follows:

- Two independent consultants, both vegetation ecologists.
- Two university academics, both with research experience in estuarine vegetation ecology.
- One government scientist from Victoria, with experience in field botany and conservation planning.

Four of the five experts were part of the team that produced the Victorian Saltmarsh Study (2011).

We first discussed the assessment of fringing vegetation in an informal workshop context with three of these experts, and defined nine candidate indicators. We then presented all the experts with the candidate indicators, and asked the experts to comment on their relevance and feasibility, and suggest what relative weight they would give each indicator. The results of this consultation are presented in Table 1. It is notable that the experts diverged substantially in their weights, as they have for other similar processes of expert weighting (e.g. Wood and Lavery 2000).

We responded to these weights, and the comments of the experts, in several ways:

- We discarded the concept of dividing the estuary fringe into two zones (The perimeter strip within 5 m of the water's edge, and the remainder of the fringing vegetation). This distinction is no longer made in the method or elsewhere in this report.
- We discarded one potential indicator that was weighted consistently low by all experts (Richness of vascular native plants in the fringe; mean weight 28%).
- We combined indicators, where the expert comments confirmed the extent of overlap between measures (Potential indicators 1,2,3,5,6 and 7 as shown in Table 1).
- We 'de-scored' one potential indicator ('Health of the dominant species' after combining it from two measures), meaning that the measure is included in the assessment so that the information is recorded, but the measure does not contribute to the score.
- We added one indicator suggested by the experts ('Percentage of fringe that is covered by built structures, as Indicator 1), which was closely related to some of the potential indicators ('Percentage of perimeter that is native vegetation', 'Percentage of fringe that is native vegetation').

This process resulted in a list of only three scored measures, which best reflected the advice and consensus view of the experts.

After these three final indicators were defined, we asked all the experts to provide new weights for these measures. All experts agreed that they should be equally weighted.

Table 1: Summary of expert consultation on the inclusion of indicators

The experts are anonymous, and abbreviated according to affiliation (A = Academic, C = Consultant, GS = Government scientist). An asterisk (*) indicates that the expert's weighting applies to a version of the measure which incorporates the modifications they suggested. The original consultation measures referred to the concept of the "perimeter", a 5-m wide strip of fringing vegetation abutting the permanently inundated portion of the estuary, readily viewed from a boat; this zone was abandoned and is no longer defined for IEC.

Some decisions are abbreviated; comb. = combine, showing the measure in brackets with which the combination occurred; mod. = modify.

The column headed "final" shows the indicator in the recommended metric, which incorporates the concept.

Potential Indicator	A1	A2	C1	C2	GS	Mean	Decision	Final
Original consultation measures								
1 Percentage of perimeter that is native vegetation	100	100	100	100	0	80	Comb. (5)	1
2 Degree of exotic invasion around perimeter	50	60	67	100	100*	69	Comb. (6)	2
3 Structure of the perimeter vegetation	50	40	67	75	100*	58	Comb. (7)	3
4 Health of the dominant species in the perimeter	50*	40	100	100	0	60	De-score	-
5 Percentage of fringe that is native vegetation	100	100	100	100	0	80	Comb. (1)	1
6 Degree of exotic invasion in fringe	100	60	67	100	100*	82	Comb. (2)	2
7 Structure of the fringe vegetation	50	40	33	75	100*	50	Comb. (3)	3
8 Health of the fringe native vegetation	50*	40	83	100	0	56	De-score	-
9 Richness of vascular native plants in the fringe	0	40	50	50	0	28	Discard	-
Potential additional measures suggested								
Percentage of fringe that is covered by built structures							Add	1
Physical evidence of detrimental human impacts							Ignore	-
Extent that the intertidal zone can retreat upland							Ignore	-

3 Recommended method for the assessment of estuarine fringing vegetation

3.1 Overview

The assessment method described below is designed to produce a single score (0–100) that quantifies the condition of fringing vegetation in an 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.

The assessment is relatively rapid, such that approximately 90% of the estuaries in Victoria should be able to be assessed by a pair of observers spending between 3 hours and 1 day in the field. The assessment includes three distinct indicators, each of which is scored on a 0–100 scale:

1. Percentage of fringe area that is covered by built structures.
2. Nativeness of the fringing vegetation.
3. Structural complexity of the fringing vegetation.

Two other parameters are also recorded, but not scored ('Health of the dominant plant species', and 'Extent of engineered hydrological modifications', see below). These additional observations may prove useful for estuary management decisions or qualitative monitoring.

The assessment requires observers who are relatively knowledgeable in estuarine ecology and estuary plants; to a degree similar to that required for habitat hectares or the IWC.

In summary, the assessment process involves the following steps:

- In the field, a map of the estuary is produced (by annotating an aerial photograph), showing the extent of the fringing vegetation, and any built structures that impinge on it.
- The fringing vegetation is mapped according to ecological vegetation classes (EVC), and divided into areas of different perceived condition. In practice, this step will often use pre-existing vegetation mapping.
- Each patch of vegetation that can be accessed is scored for its degree of perennial weed invasion, and its structural resemblance to a relevant benchmark. It is expected that sufficiently detailed examination of virtually all patches will take between 2 and 10 minutes each, with only the very largest and most complex patches requiring examination of up to 30 minutes (see 'Recommended coverage and intensity of assessment', below); in other words, the assessment is rapid, not exhaustive.
- Some additional observations are recorded on the score sheet, relating to 'Health of the dominant plant species' and 'Extent of engineered hydrological modifications'.
- Back in the office, the areas that could not be observed are provided with estimated scores, based on the areas that were observed.
- The areas of all relevant polygons are calculated, and a score is produced using the formulae described below.
- The uncertainty attributable to incomplete observation is quantified, by producing an upper and lower score, assuming the best and worst possible scores, respectively, for the un-observed areas.

The following sections provide a detailed description of the assessment. An example score sheet is provided in Appendix 2.

3.2 Indicator 1: Percentage of fringe that is covered by built structures

This indicator assesses the percentage (0–100%) of the fringe area that is composed of built structures. Built structures are assumed to be detrimental because they remove fringing vegetation and disrupt ecological processes. The higher the percentage of built structures, the lower the score. Thus, this indicator is effectively assessed against a single baseline (i.e. 0% built structures) that applies to all estuaries, allowing comparison between estuaries and longitudinal comparisons on a single estuary.

The assessment requires the following steps:

1. A map of the estuary fringe is produced, showing all portions that are built structures. This map should be at a spatial resolution that permits structures larger than 10 x 10 m to be distinguished.
2. The total area of the fringe is calculated and recorded (F).
3. The area covered by built structures is calculated and recorded (BS).
4. A score (0-100) is derived, using the following formula:

Score = 100 – (100 x (BS / F)).

The score for this indicator is recorded to the nearest percentage integer. The score sheet requires the map and the raw areas to be recorded. No uncertainty will be recorded for this indicator.

This indicator may be assessed from aerial imagery with high resolution from aerial photography (with pixel sizes <1 m).

3.3 Indicator 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. This indicator is effectively assessed against a common baseline (i.e. 0% exotic) that applies to all estuaries, allowing comparison between estuaries and longitudinal comparisons on a single estuary.

The scoring sheet for this indicator will require estimates of cover, with uncertainty (i.e. plausible bounds) recorded.

The assessment requires the following steps:

1. A map is produced, showing all areas that are fringing vegetation (F) (i.e. all areas of the fringe that are not built structures, in the same map produced for indicator 1).
2. This area is divided up into patches (1–n), with each patch representing an area that is a single EVC in a single condition state. The area of each patch is recorded (A1, A2…An).
3. The percentage cover of all perennial vegetation is estimated for each patch (CP1, CP2…CPn).
4. The percentage cover of all exotic perennial species is estimated for each patch (CE1, CE2…CEn)
5. A score (0-100) is derived, using the following formula:

Score = 100 – ((100 x (CE1/CP1) x (A1/F)) + (100 x (CE2/CP2) x (A2/F)) … + (100 x (CEn/CPn) x (An/F)))

The score for this indicator is recorded to the nearest integer. The score sheet requires the map and all raw estimates to be recorded.

Areas of bare ground should be included, and CE1/CP1 should take a value of 0 (meaning that bare ground does not cause a score reduction).

This indicator will not be able to be assessed accurately from aerial imagery, and field assessment is recommended. If some patches cannot be directly observed, the process described below (‘Expressing uncertainty for estuaries with partial site coverage’) should be applied.

3.4 Indicator 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 vegetation types (i.e. EVCs) that are present. This indicator produces a score that is calculated with reference to benchmarks specific to each EVC. This best enables each estuary to be compared with its own condition at previous dates (longitudinal studies). The benchmarks (for IWC and Habitat Hectares) have been composed so that their scores are reasonably consistent with each other, and some coarse cross-estuary comparison is appropriate, provided caution is exercised in the interpretation of results.

The scoring sheet for this indicator will require raw estimates of cover, with uncertainty (i.e. plausible bounds) recorded.

The assessment requires the following steps:

1. A map is produced, showing all areas that are fringing vegetation (F) (i.e. all areas of the fringe that are not built structures, in the same map produced for indicator 1 and 2).
2. This area is divided up into patches (1-n), with each patch representing an area that is a single EVC in a single condition state. The area of each patch is recorded (A1, A2…An). These are the same patches required for indicator 2.
3. For each EVC, the appropriate benchmark is consulted (see above; DELWP 2016b), which specifies the life-forms that are expected to be present (Listed under "Critical Lifeform Groups" in IWC), and the cover which species within that life are expected to attain (E1–En, expected covers for lifeforms in an EVC with n lifeforms).
4. For each patch, the actual cover of native species attributable to each of the benchmark lifeforms should be estimated (O1–On, observed covers for lifeforms in an EVC with n lifeforms).
5. For each patch, a score (0–100) is derived using the following formula:

   Patch Score = 100 x (O1 + O2 + …. On) / (E1 + E2 + … En)

   If O exceeds E, O is assumed to be equal to E for the purposes of scoring.

   In polygons of bare ground, the patch score should be set to 100.

6. An unweighted score for the indicator is then derived, across all patches, using the following formula:

Score = ((Score patch 1) x (A1/F)) + ((Score patch 2) x (A2/F)) … + ((Score patch n) x (An/F)))

The score for this indicator is recorded to the nearest integer.

This indicator will not be able to be assessed accurately from aerial imagery, and field assessment is recommended. If some patches cannot be directly observed, the process described below ('Expressing uncertainty for estuaries with partial site coverage') should be applied.

3.5 Recommended coverage and intensity of assessment

The Indicators described above could be scored based on estimates from rapid assessments, or on measurements from lengthy and extensive visits. Given that the IEC is intended to be a rapid assessment tool, the following guidance is provided on the appropriate intensity and coverage of assessment:

- Estuaries with a fringe area <500 ha should be assessed by a pair of observers spending <1 day in the field.
- More than 1 day should be spent only on estuaries with a fringe area >500 ha if more field time would increase the coverage of directly observed polygons above 25% of the fringe area.
- No longer than 3 days should be spent in the field to assess any single estuary.
- Assessors should try to observe all the EVCs in each estuary.
- Assessors should try to observe all main land-use types in each estuary, so that a wide range of condition states is captured.

For some estuaries, the cost of visiting them at all is not considered justified. In these cases, assessments should be made from aerial photography only. In such cases, scores should be assigned based on assessments made in estuaries in similar contexts, in polygons of similar EVC and landscape position. Assessment by aerial photography, without any field visits, should occur in the following circumstances:

- If the estuary fringe is less than ~2 ha in extent, and the estuary is relatively inaccessible. This is expected to apply mostly to parts of Wilsons Promontory and East Gippsland).
- Reasonable attempts to access the estuary are likely to result in less than 25% of the estuary being directly observed. This constraint may apply in estuaries surrounded by multiple parcels of private land, or in areas where road access is very limited.

3.6 Combining the indicators to produce a final score

Each of the three indicators described above produces a score ranging between 0 and 100. These will be combined with an arithmetic mean (simple average). This is equivalent to adding them with equal weights.

3.6.1 Expressing uncertainty for estuaries with partial site coverage

Given the constraints on field effort detailed above, it is necessary that scores can be derived from estuaries that are assessed on the basis of a partial examination. To achieve this, scores will be reported as best estimates with upper and lower bounds, that represent the degree of uncertainty introduced to the score owing to the incompleteness of the assessment (noting that there will be additional uncertainty due to other factors). The upper bound will represent the highest score possible, given what is possible in the areas that were not seen, likewise for the lower bound. The more of the estuary that is observed, the narrower these bounds will be.

To achieve this, the following steps will be followed:

- For Indicators 2 and 3, all polygons on the map will be annotated as to whether they are “directly observed” or “not observed”. It is acknowledged that for many polygons, a partial or imperfect observation will be made (e.g. from a distance through binoculars, or of only one small portion of a larger polygon). In these cases, the most appropriate category must be selected, at the discretion of the observer. It is noted that some EVCs vary very little over large areas, and may be adequately observed with only cursory effort (e.g. Mangrove Shrubland). Other EVCs may vary substantially in regard to species composition, degree of exotic invasion and structure, and these may require more intensive survey effort to warrant a designation of “directly observed”. Regardless of the vegetation, it is considered inappropriate to consider any area to be “directly observed” that is more than 250 m distant from a point that was observed.
- The polygons that were “not observed” should be endowed with data, based on extrapolation from the polygons that were “directly observed”, by applying the scores from polygons with the same EVC and context. The overall score for each indicator should be derived from this extrapolation and reported as the ‘best estimate’.
- The polygons that were “not observed” should then be re-assigned values that produce a zero score (100% exotic cover; none of the benchmark lifeform groups). A new overall score for the indicator should be produced using these scores, representing the lower bound. A similar process should be repeated with the highest score possible for each polygon “not observed”, to derive the upper bound. This process may lead to upper and lower bounds of different sizes.
- For Indicator 1, recent aerial imagery will be used to map built structures in all areas, including those which are not visited, and a single score should be derived in the absence of a site visit, without any expressed uncertainty due to partial site coverage.
- The overall estuary score should combine the best estimates for indicators 1, 2 and 3, reported with the most extreme combination of upper and lower bounds.

3.7 Variables that are recorded but not scored

Several additional variables are considered valuable, because they provide information that is useful for managing estuaries and tracking changes in estuarine ecology. For this reason, they should be assessed and recorded, although they do not contribute to the score. These are listed below, with the reasons for their exclusion from scoring, and the value of recording them.

Several other variables were considered for scoring or recording, but were discarded altogether. These are described in Appendix 4.

3.7.1 Health of the dominant plant species

Declines in the condition of estuary fringing vegetation may manifest through declines in the health of individual plants. For example, if hydrological flows are altered, some species that no longer experience their preferred water regime may decline and die.

This potential indicator was excluded from scoring because it was considered too difficult to reliably distinguish declines in health representing loss of condition, from natural changes of little management concern, such as seasonal growth cycles or changes related to natural phenomena such as sand movement or succession. It is also difficult to score quantitatively.

Observers will assess the health of the five plant species which contribute the most cover within each EVC, and rate their health as a percentage of the 'degree of health' expected, at that time of year, for that species. It is expected that these data will be highly subjective and imprecise.

3.7.2 Extent of engineered hydrological modifications

Even slight changes to hydrology potentially threaten estuary vegetation because they can alter the growing conditions for plants, leading to the competitive exclusion (or death) of some species, and their replacement by others, often including exotics. It may result from activities or structures that change the flows from the sea (e.g. entrance opening, sea walls, culverts) or the pattern of flows from the catchment (e.g. dams, culverts, stormwater inputs).

This potential indicator was excluded from scoring for three reasons:

- The hydrology of estuaries is complex and varies among sites, so that it is difficult to equate the degree of ecological change with any simple measure based on the extent of engineering works (e.g. a single poorly designed culvert may do far more damage than a large pond).
- Sensible responses to sea-level rise may involve engineering works, both to protect human infrastructure, and to facilitate protection or migration of ecosystems. Penalizing all sites that are engineered may be counter-productive in such a context.
- Estuarine vegetation may have reached a relatively stable equilibrium after accommodating hydrological changes imposed a long time ago. There may be no good ecological reason to penalize such sites.

This indicator will be assessed qualitatively. Observers will note whether the estuary has experienced any of the following modifications which may impact the fringing vegetation:

- 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.

3.8 Definitions

The description and assessment of the indicators rests on a number of concepts which are defined in prior publications or require definition here. This section provides those definitions.

3.8.1 Benchmarks

Each EVC is accompanied by a benchmark, which outlines 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).

For IEC fringing vegetation assessments, benchmarks should be taken from DELWP (2016b), which describes the benchmarks for IWC assessments, and which includes the benchmarks for the recommended 'provisional EVCs' described by the Victorian Saltmarsh Study (2011). The lifeform list and threshold cover values listed under "Critical Lifeform Groups" should be used.

In the unlikely event that a patch of estuarine vegetation does not conform to an EVC with a benchmark listed in DELWP (2016b), a Habitat Hectares benchmark for terrestrial vegetation may be used.

3.8.2 Built structures

Built structures include anything made from concrete, wood, brick, or formed earth. They also include permanent open water in artificial impoundments. They include the following:

- the footprint of 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.

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.

The relationship between the fringe, the fringing vegetation (both defined below) and built structures is shown in Figure 2, using the Painkalac Creek estuary as an example.

3.8.3 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.

3.8.4 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 considered suitable for assessment with the IEC 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 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.

3.8.5 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.

3.8.6 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. The relationship between the fringe, the fringing vegetation and built structures is shown in Figure 2.

3.8.7 Fringing vegetation

Fringing vegetation is that vegetation above the permanently inundated portion of the estuary, which naturally experiences some hydrological influence from the waters of the estuary. 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). The relationship between the fringe, the fringing vegetation and built structures is shown in Figure 2.

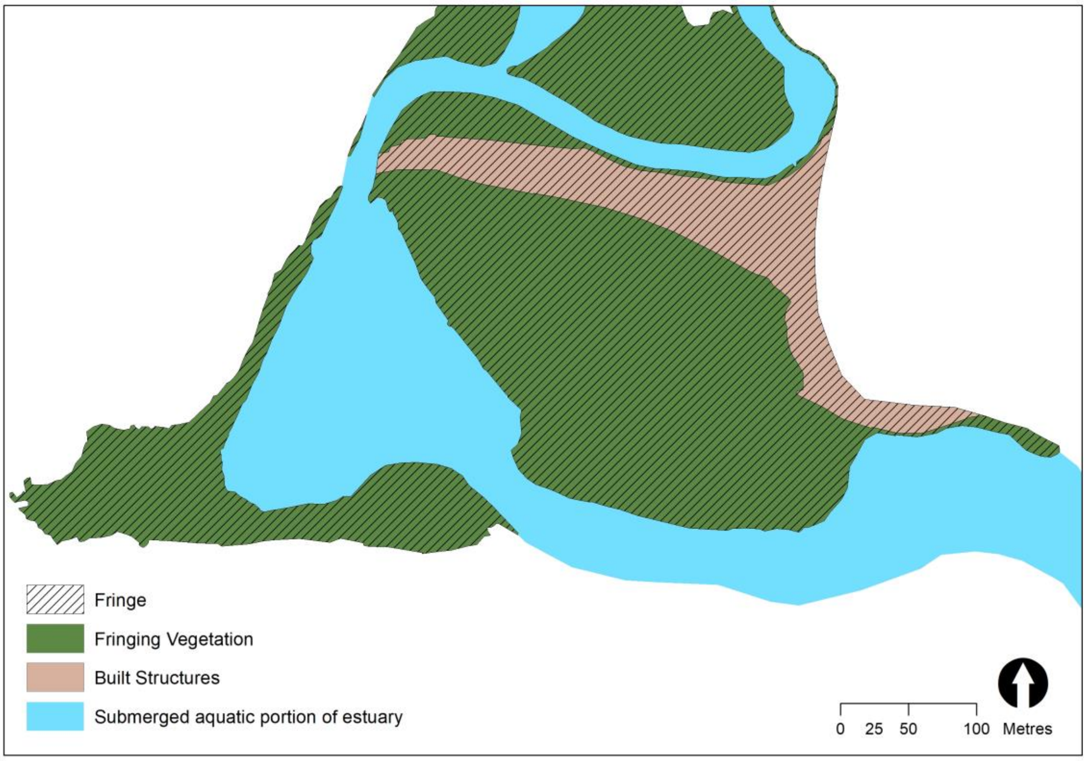

Figure 2. Schematic diagram of the zones defined here.

This diagram is based on the Painkalac Creek estuary (Aireys Inlet), modified from Sinclair and White (2005). Note that the 'fringe' is divided into 'Fringing vegetation' and 'built structures'. Note that the Great Ocean Road bridge (and its associated fill) is considered a built structure while it crosses the fringe, but is considered irrelevant once it crosses open water.

Delineation of the fringing vegetation may be difficult in practice, for several reasons:

- The lower boundary of the fringing vegetation may be ambiguous, because the extent of the "permanently inundated" portion of the estuary may not be obvious at the time of assessment. For estuaries or portions of estuaries that are fringed by mangroves, the seaward margin of the mangroves should be considered the lower boundary of the fringing vegetation (i.e. the mangroves are included). For estuaries lacking mangroves, the boundary of the fringing vegetation is defined by the estuaries layer in the DELWP Corporate Spatial Data Library (which roughly corresponds to the lower edge of the intertidal zone). Seagrass vegetation (vegetation dominated by species of *Zostera*, *Heterozostera*, with little or no mangrove cover) is always excluded from the fringing vegetation, and treated as part of the "permanently inundated" portion of the estuary, even if it is exposed at the time of assessment, as such vegetation occasionally is. Water Matts and Tassels (*Ruppia* and *Lepilaena* species) are included when growing in pools surrounded by intertidal vegetation, but otherwise excluded.

- The landward boundary of the fringing vegetation may be ambiguous, because the inland extent of the hydrological influence of the estuary is not obvious. For the purposes of the IEC, the fringing vegetation includes:
    - 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) (or any determination of this zone which supersedes these studies), and
    - all wetlands or damplands which show a brackish influence in their species composition (as determined by a botanist, based on the occurrence of salt-tolerant species such as *Juncus kraussii*, *Selliera radicans*, *Samolus repens*, etc.), and which are contiguous with the flats of the estuary (i.e. excluding any nearby wetlands of this type which are separated by raised ground, dunes, etc.).
- Portions of the fringing vegetation may be hydrologically disconnected form the estuary by human impacts (such as sea walls, roads). The full pre-impact extent of the fringing vegetation must be assessed for IEC, requiring that the 'pre-1750' boundary of the fringing vegetation be delineated. This can be done using whatever means are appropriate (field inspection, historical maps, elevation data). For intertidal areas, these areas have been defined by the Victorian Saltmarsh Study (2011) and further described in Sinclair and Boon (2012). The areas delineated by Sinclair and Boon (2012) should be used unless field examination shows them to be incorrect.
- The extent of the fringe may be ambiguous for estuaries that meet low-energy coasts fringed by a continuous intertidal zone (e.g. Western Port, Corner Inlet). In these cases, multiple estuaries may be joined by a continuous intertidal zone. In theory, only that portion of the intertidal zone with some influence from each stream is relevant, however this is virtually impossible to determine in practice. For this assessment, the fringing vegetation relevant to each estuary must be divided from the coastal intertidal zone. It is suggested that this is done by throwing a buffer around the "permanently inundated" portion of the estuary, with the buffer distance determined by the flow in each stream. This is based on the assumption that large streams would exert more influence on the coastal zone than small streams. The resulting 'flow-based buffer' should only apply to estuaries with fringe boundaries that are ambiguous because they meet a coastal intertidal zone. Appendix 3 provides a list of the estuaries for which a flow-based buffer is required, and provides the flow accumulation data and the suggested buffers for those estuaries. Where the buffers of two estuaries overlap in the middle (e.g. two nearby large streams), the coastal zone should be apportioned between the streams with no overlap, and the position of the boundary between the streams determined by the relative sizes of their buffers.
- Estuaries may be joined to very extensive lagoon systems which run parallel to the coast and extend far from the estuary mouth. For the purposes of IEC, the entirety of such systems is included provided they meet the other criteria (e.g. they have a brackish influence associated with the estuary). In rare cases, two estuaries may be linked via a continuous marshland strip. For example, Merriman Creek, a minor stream at Seaspray in Gippsland, is connected via marshland to the extensive Lake Reeve system (over 30 km long), which eventually meets the Gippsland Lakes. In this case, an arbitrary boundary must be drawn between the two systems. The same approach should be used as that detailed above for estuaries that "join" via coastal intertidal marshes.

To avoid inconsistency in application, the extent of fringing vegetation will be defined for each estuary during the first assessment period, and will then remain unchanged for future assessment.

3.8.8 Life-forms

'Life-forms' 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.

Native vegetation types (Ecological Vegetation Classes (EVCs))

In Victoria, patterns of different vegetation types are generally 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. The DELWP website maintains a list of terrestrial vegetation EVCs, along with descriptions of the vegetation and ‘benchmarks’ (see above where?).

3.8.9 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.

3.9 Fringing vegetation pilot study

The fringing vegetation assessment method was trialled on six estuaries, during the spring of 2017. The estuaries were selected to represent a range of ecological contexts, vegetation types, estuary sizes, and levels of degradation. The selected estuaries are described in Table 2.

The aims of the pilot study were:

- To complete the first year's monitoring for the selected estuaries,
- To ensure that the assessment method was practical, and recommend any necessary changes,
- To record how much effort was required to achieve a reasonable coverage of assessment for each of the six estuaries.

The assessment method described above (see "Method for the assessment of estuarine fringing vegetation") has already been refined, based on the pilot.

Table 2: The characteristics of the pilot study estuaries.

The estuaries are listed from west to east.

	Anglesea	Thompson	Barwon	Tarwin	Stockyard	Franklin
Context and impacts						
Size (ha of fringe)	24	415	3227	1418	44	265
Predominant surrounding land use	Urban	Agricultural	Agricultural	Agricultural	Agricultural	Agricultural
Seawalls?	Minor	Minor	Minor	Extensive	Extensive	Extensive
Habitat types						
Mangroves?	None	Minor	Moderate	Moderate	Major	Major
Saltmarsh?	Moderate	Major	Major	Moderate	Moderate	Moderate
Marshlands?	Major	None	Major	Major	Minor	Minor
Pools?	Minor	Minor	Minor	Minor	Minor	Minor
Swamp Scrub?	Major	None	None	None	Minor	Moderate

3.9.1 Pilot study results

The assessment method was applied to the six estuaries, between 25th September and 24th October 2017. The results of these assessments are presented in Table 3. Figure 3 represents the scores graphically, with uncertainty attributed to incomplete area survey. Additional uncertainty from other sources is not shown (e.g. uncertainty of visual estimates, the heterogeneity within polygons, and error in drawing polygons).

Table 3: The IEC fringing vegetation scores for the six pilot study estuaries.

Only the best estimate is presented. See Figure 3 for a representation of uncertainty.

Indicator	Anglesea	Thompson	Barwon	Tarwin	Stockyard	Franklin
1: Built structures	73	94	99	97	95	98
2: Nativeness	99	95	89	49	49	93
3: Structural Complexity	63	87	90	50	39	95
Score	**78**	**92**	**93**	**65**	**61**	**95**

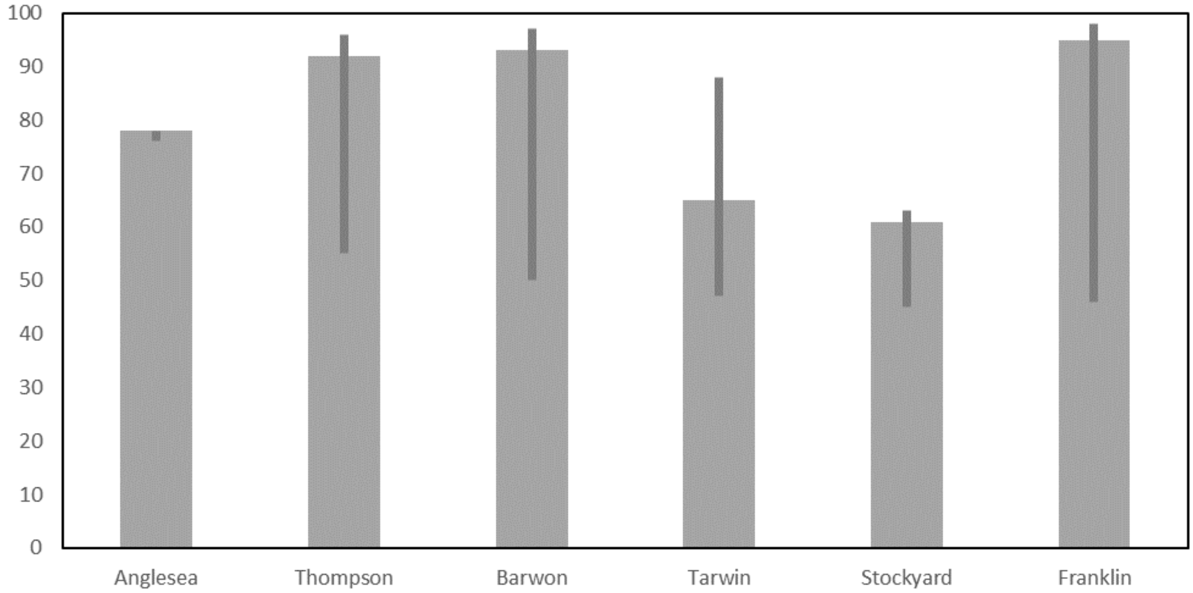

Figure 3. IEC Fringing vegetation scores for the estuaries in the Pilot Study.

The final score is represented by the bar. Error bars represent the uncertainty that is due to incomplete survey coverage, as described in the text.

The results may also be represented spatially. Figures 4 to 6 show examples of the polygons that were assessed, and used to derive the scores, for the Barwon and Thompson estuaries. These estuaries were chosen for display because they are particularly complex. Figure 4 shows the extent of on-ground assessment. Figure 5 shows the distribution of built structures (used to assess Indicator 1) and the nativeness of each polygon (used to assess Indicator 2). Figure 6 shows the score for the structural complexity of the fringing vegetation in each polygon (for Indicator 3).

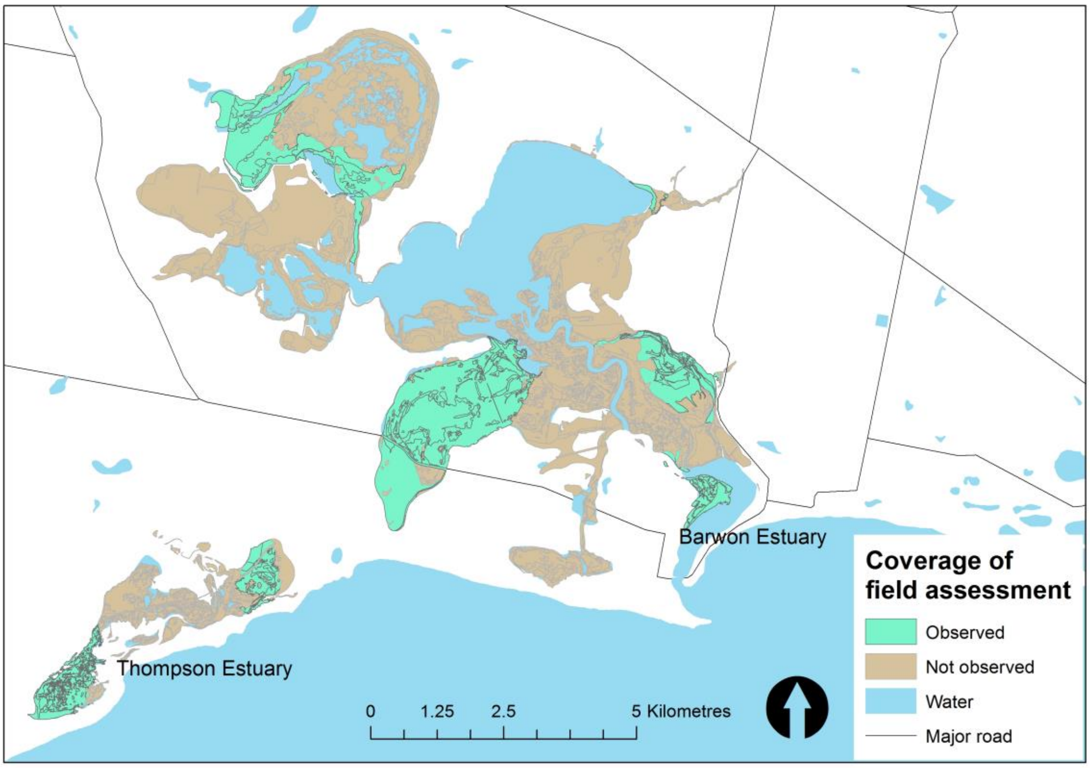

Figure 4. The coverage of on-ground assessment in the Barwon and Thompson estuaries.

30% of the Barwon was directly observed, 39% of the Thompson. These levels of assessment lead to the uncertainty shown in Figure 3. It can be seen (with reference to Figures 5 and 6) that the areas assessed were targeted so that a wide range of condition states were covered.

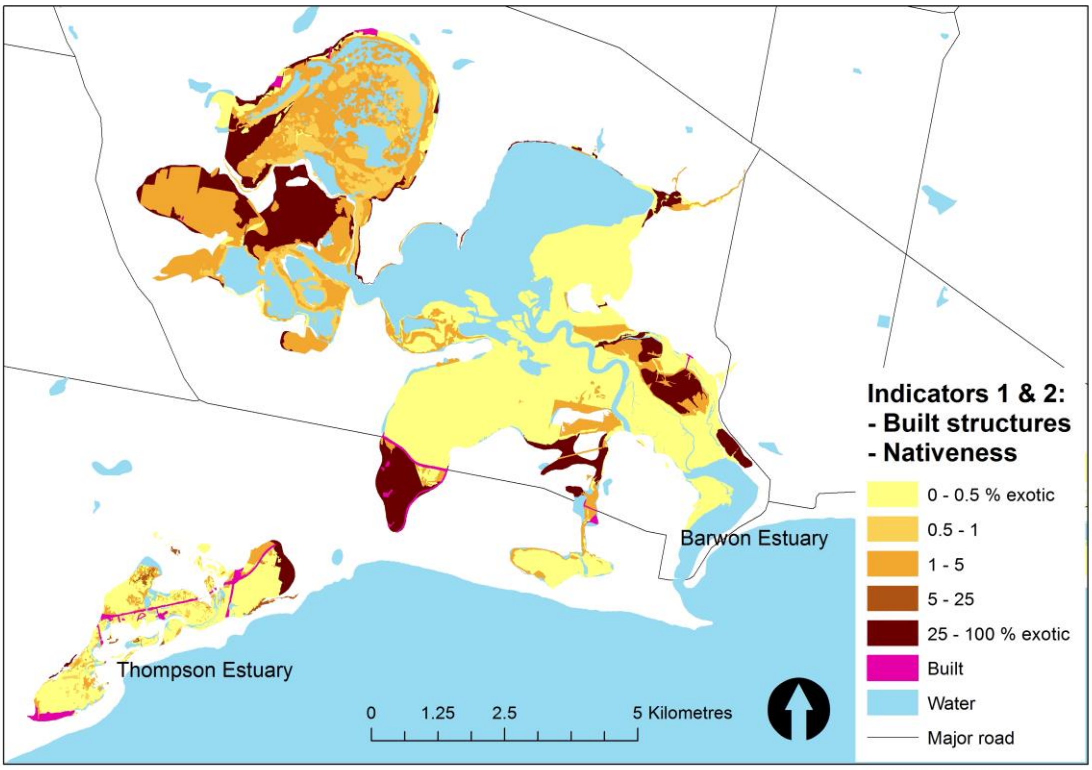

Figure 5. The spatial data used to score Indicators 1 and 2, for the Barwon and Thompson estuaries.

For component 1, the polygons that are designated "built structures" are shown. Only a relatively small proportion of these estuaries is "built". For component 2, the proportion of the perennial vegetation that is exotic is shown for each assessed polygon (CE1/CP1; refer to p23).

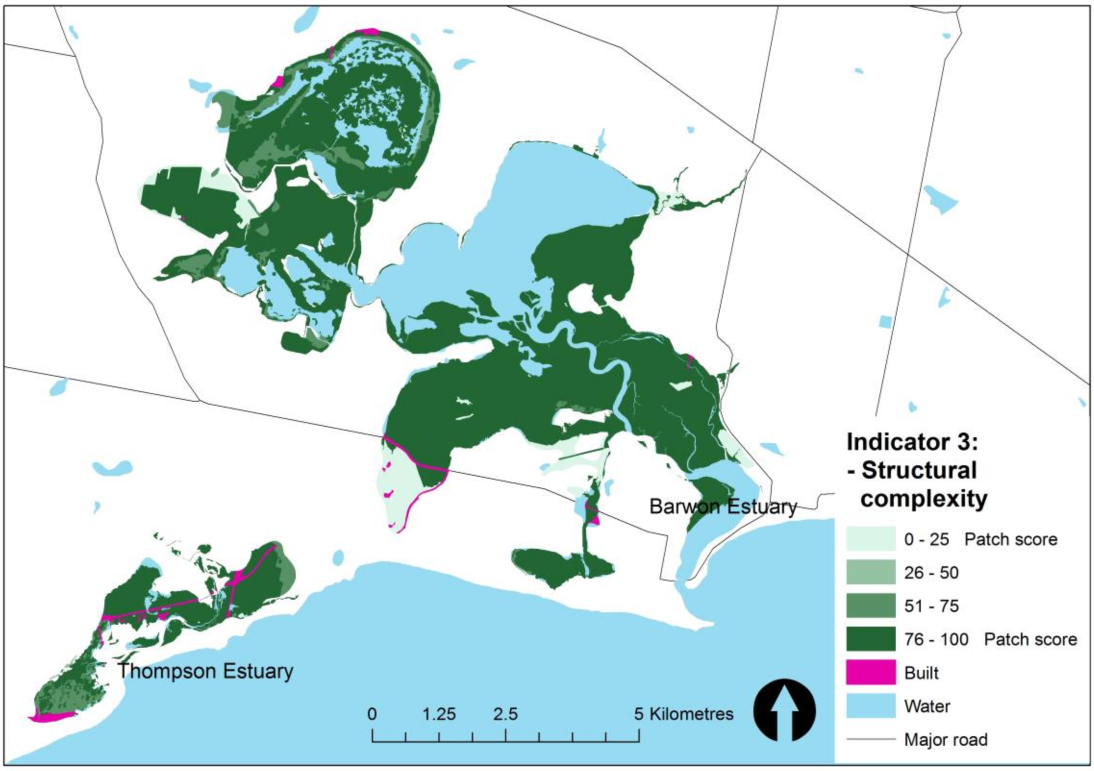

Figure 5. The spatial data used to score Indicator 3, for the Barwon and Thompson estuaries.

The patch score for each polygon is shown; which compares the observed to the expected lifeform composition (refer to p24).

3.9.2 Survey effort required

An important aim of the case studies was to document how much effort was required to achieve the results reported above, with the attendant degree of uncertainty attributable to incomplete survey, which is assumed to represent a reasonable degree of uncertainty. The advice provided above about the appropriate intensity and coverage of assessment was based on the experience of the pilot study.

Table 4 shows the number of hours spent in the field assessing each estuary, and the proportion of the area that was deemed to be "directly observed". It is important to note that these times include only the time spent observing the estuary, not the travel time to and from the estuary, nor any preparation time. For the purposes of future costing, this time needs to be separately estimated.

Table 4 also shows the amount of time spent undertaking the GIS analysis required to derive the scores for each estuary. It is important to note that this work benefitted from existing data layers, such that most of the polygon boundaries were already defined (Victorian Saltmarsh Study 2011, Sinclair 2010). Nevertheless, the GIS component was found to be a time-consuming component, at times taking as much time as the fieldwork component. It is important to note that the Barwon, Thompson and Tarwin estuaries are three of the largest and most complex estuaries in Victoria. They represent close to the maximum amount of time an assessment would be expected to take.

Table 4: The effort required to assess the pilot study estuaries.

	Anglesea	Thompson	Barwon	Tarwin	Stockyard	Franklin
Dates assessed	24 Oct	11 Oct	12, 24 Oct	25, 26, 28 Sep	27 Sep	27 Sep
Hours (field)	4	6	11	18	2.5	4
Hours (GIS)	2.5	5	10	12	2	2
Hours (excl. travel)	6.5	11	21	27	4.5	6
Hectares of fringe	24	415	3,227	1418	44	265
% “directly observed”	97%	39%	30%	38%	74%	21%

3.9.3 Key learnings from the pilot study

This section discusses some of the issues that were encountered during the case studies. The lessons learnt have been incorporated into the directions for assessment given above (see “Method for the assessment of estuarine fringing vegetation”, above).

Utility of the existing vegetation maps

Much of the estuarine vegetation of Victoria has already been mapped by previous studies. These include the Victorian Saltmarsh Study (2011), which mapped most intertidal vegetation to EVC, along with several regional studies, which have mapped some estuarine vegetation above the intertidal zone (e.g. Sinclair and Sutter 2008, Osler et al. 2010, Sinclair 2010). Almost all the existing polygons were adequate to be used to guide field assessments, and were a helpful prompt for EVC delineation. It is estimated that these pre-existing spatial data saved many tens of hours of polygon creation and editing. They will also be useful to guide assessments in estuaries that are assessed only from aerial photographs, since the prior mapping often records dominant species and EVCs from past field visits.

Assessment of areas undergoing rapid ecological change

When the hydrology of an area is altered, the vegetation may undergo rapid changes. Whether these changes are undesirable (the original vegetation is destroyed), or desirable (a new system is formed), is rarely clear and is inherently subjective.

An example of the degree of complexity involved was encountered in the Anglesea River estuary, at Coogoorah Park. This area was once an extensive peat swamp. It ignited during the Ash Wednesday fires in 1983, and burned for a significant period. To extinguish the fire, it was necessary to use heavy earth moving equipment to create channels to allow the river to submerge the peat swamp. Later the area was landscaped, and turned into a recreational area (Teague et al. 2015). Throughout this period, the Anglesea River received regular flows (~4.5 ML/day) from the upstream Alcoa coal mine. The recent closure of the mine resulted in much reduced flows, and the exposure of acid sulphate soils (GHD 2016). Currently, water levels within the estuary are being actively managed (above 1.3 m asl) to prevent further exposures of acid sulphate soils, by pumping water from the disused mine site into the river. These complex changes have resulted in shifting vegetation patterns, which have been influenced by active regeneration efforts. The area remains in a state of flux.

This area offered a particularly interesting and difficult example for the application of a condition assessment. When assessed in the pilot, we first had to judge the extent of the estuary fringe. This was difficult because the salinity regime of the former swamp is no longer evident (although it was presumably somewhat fresher than today). We assumed that all areas of wetland with a clear brackish element were part of the assessable estuary fringe. This was the most cautious approach, given this would maximise the score for the estuary, as the area is largely covered in native vegetation. It was then necessary to decide which areas were built, and which were part of the fringing vegetation. We assumed that all areas of raised soil were built, while all flat areas subject to inundation were not built (acknowledging that some may have been flattened by an excavator in the 1980s).

For areas that support native vegetation, we applied the following principle, that should be applied broadly: an area undergoing change should not be 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. Such an assessment should use whichever EVC benchmark will return the highest score for the polygon. If, however, the change is from a native EVC, to some other assemblage of plants that does not resemble any estuarine EVC (e.g. exotic vegetation), then the benchmark for the original vegetation should be used, and the patch will be scored down.

The influence of the flow-based buffer on the score

Twenty-one of Victoria's estuaries have no obvious edge to their fringing vegetation, and merge into the nearby coastal marsh vegetation (described further under 'Definitions'). For these estuaries, an arbitrary buffer has been used to define 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 (see Appendix 3).

The size of this arbitrary buffer will have a large impact on the scores for all components, 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 for each estuary, but it does mean that the score comparison of one estuary to another is dependent on the arbitrary choice of buffer size for these twenty-one estuaries.

The pilot study highlighted this issue. Both the Franklin River and Stockyard Creek required buffers to delineate the extent of their fringes. Both estuaries are in a very similar context (low energy coastline in Corner Inlet), and support similar vegetation (mangroves, saltmarsh) with similar surrounding land-uses (bund walls protecting cattle pasture). Despite this, their scores are very different (Franklin River scored 96 and Stockyard Creek scored 59). This is largely because 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 Table 3). However, the degree to which the scores differ depends very much on the size of the delineated 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.

Ecological and plant identification skill

The methods require a reasonably high degree of ecological knowledge and plant identification skill; about equivalent to the degree of knowledge required for habitat hectares, or IWC. An assessor must be able to identify EVCs and the predominant species in them, and perennial weeds from native species. This degree of competence is reasonable to expect of any ecological consultant or suitably-trained university student.

Assessment from bund walls and with binoculars

We found the extensive bund wall system in Gippsland useful for accessing parts of the Tarwin estuary and Stockyard Creek. Not only did these walls provide an efficient way of navigating the perimeter of these estuaries, it also provided an elevated view. This, combined with the use of binoculars, was useful for viewing inaccessible components of the estuary (i.e. private land without access consent). We also utilised public roads around the estuaries as vantage points for viewing private or inaccessible land.

The need for accurate and legible annotation of maps

The need for clear and legible field notes may seem obvious, but the need to clearly ensure maps are annotated with the same numbers that are attributed to polygons is crucial.

Time needed for GIS analysis

A key learning from the pilot study was that the time needed for the GIS analysis was substantial. As already mentioned, the existing layers derived from previous studies saved much time. However, the time needed to interpret field notes, adjust and attribute polygons in GIS layers should not be underestimated.

4 Conclusion

The pilot study provided an opportunity for testing the proposed method. We believe that the method was able to meet the needs of the IEC, being relatively quick to implement and reproduceable by different operators. The assessment method produces a single score quantifying the condition of fringing vegetation in an estuary.

The three distinct indicators allow managers and planners to rapidly understand which issues are affecting each estuary, and consider land management interventions accordingly. For example, the pilot study clearly showed that the fringing vegetation on Anglesea estuary has been damaged and restricted by prior building works (Indicator 1), but that the remaining vegetation is relatively free from weeds and retains its expected structure (Indicators 2 and 3). In contrast, the fringing vegetation of Stockyard Creek has not been replaced to the same degree by built structures (Indicator 1), however much of the vegetation has been converted to exotic pasture (Indicator 2) with a simplified structure (Indicator 3).

The proposed assessment method for estuary fringing vegetation is considered suitable for:

- contributing to the periodic condition reporting of all estuaries in Victoria
- providing information to assist in the prioritisation of management investment between estuaries, and
- informing a baseline for assessing long-term and large-magnitude changes in resource condition.

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6 Appendix 1: Field Assessment sheet

A blank field assessment sheet is included below, along with an example of a sheet, filled out to show a dummy assessment; in this case of “Fake Creek”, a small estuary imagined to be in a relatively unvisited portion of the Gippsland coast closely surrounded by agriculture.

The abbreviations shown on the dummy field sheet are summarised directly from the benchmarks (DELWP 2016b): MSSH: Medium to small succulent herbs; MSS: Medium to small shrubs; MNG: Medium (to tall) non-tufted graminoids, SH: Small (to medium) herbs, MTS: Medium to tall shrubs; SNG: Small (to medium) non-tufted grasses; SH: Small (to medium) herbs; MG: Medium (to tall) graminoids.

Assessment of Fringing Vegetation for Index of Estuary Condition

Estuary Name: Fake Creek Date of assessment: 11th Jan 2018

Assessors: Sinclair + Kohout

Component 1: NA- to be completed on GIS

Component 2:

Patch	EVC/description	Directly observed?	Estimated cover perennial vegetation	Estimated cover exotic perennials
1	Coastal Saltmarsh – Wet Saltmarsh Herbland	✓	50	0
2	" – Wet Saltmarsh Shrubland	✓	60	0
3	Estuarine Wetland – Few weeds	✓	85	1
4	" – Weedy	✓	90	15
5	Estuarine Scrub – observed, weedy	✓	99	35
6	" – Not observed, assumed like 5.	✗	99	35

Component 3:

Record the lifeform from the benchmark in the grey box. Record the expected benchmark cover (E) and the observed cover (O).

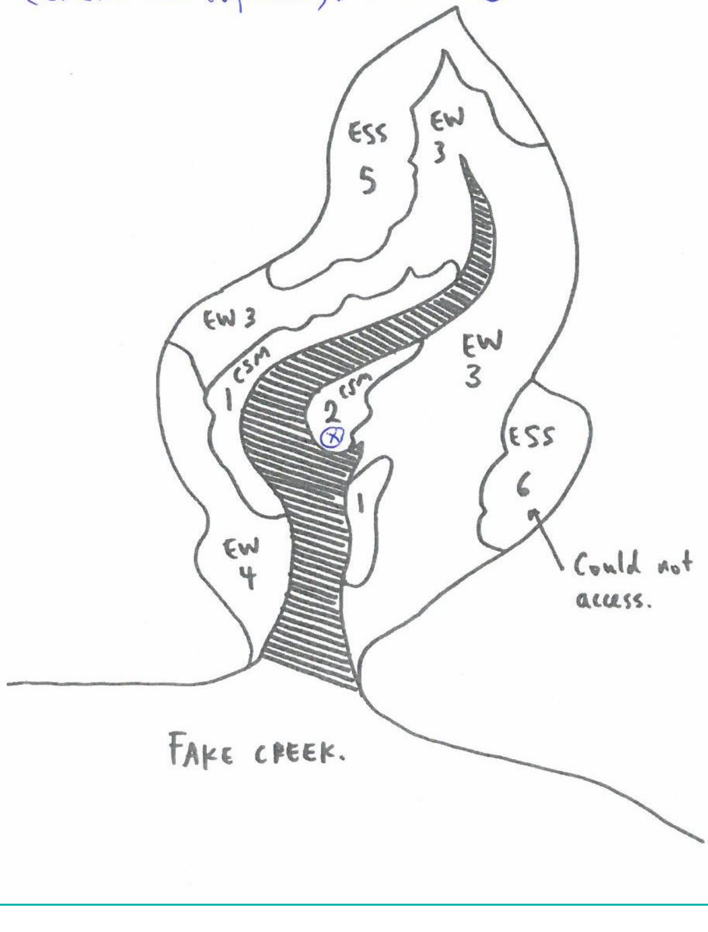
Patch	1	2	3	4	5	6						
Lifeform 1	MSSH	MSS	MNG	MNG	MTS	MTS						
E1	30	20	30	30	15	15						
O1	50	15	85	85	20	20						
Lifeform 2		MSSH	SH	SH	SNTG	SNTG						
E2		5	5	5	1	1						
O2		45	10	10	5	5						
Lifeform 3					SH	SH						
E3					10	10						
O3					2	2						
Lifeform 4					MG	MG						
E4					1	1						
O4					20	20						
Lifeform 5												
E5												
O5												

Unscored components (whole estuary):

Health of five most abundant species	
Species	%
1. Juncus kraussii	100
2. Melaleuca ericifolia	100
3. Samolus repens	100
4. Sarcocornia quinqueflora	100
5. Tectocornia arbuscula	60

Hydrological Mods (Y / N)	
Sea walls?	No
Tidal inflow restrictions?	No
Stream restr. (w/n 100 m)	No
Artificial freshwater input?	No

Notes: Tectocornia damage and decline due to sand movement (erosion and deposition). Marked ⊗



Assessment of Fringing Vegetation for Index of Estuary Condition

Estuary Name: ____________________ Date of assessment: _________________

Assessors: ____

Component 1: NA- to be completed on GIS

Component 2:

Patch	EVC/description	Directly observed?	Estimated cover perennial vegetation	Estimated cover exotic perennials

Component 3:

Record the lifeform from the benchmark in the grey box. Record the expected benchmark cover (E) and the observed cover (O).

Patch												
Lifeform 1												
E1												
O1												
Lifeform 2												
E2												
O2												
Lifeform 3												
E3												
O3												
Lifeform 4												
E4												
O4												
Lifeform 5												
E5												
O5												

<u>Unscored components</u> <u>(whole estuary):</u>

Health of five most abundant species	
Species	%
1.	
2.	
3.	
4.	
5.	

Hydrological Mods (Y / N)	
Sea walls?	
Tidal inflow restrictions?	
Stream restr. (w/n 100 m)	
Artificial freshwater input?	

Notes:

7 Appendix 2: Buffer distances for estuaries that require buffers

The assessment method described in this report requires that the extent of the fringing vegetation is defined spatially. Fringing vegetation is "that vegetation above the permanently inundated portion of the estuary, which naturally experiences some hydrological influence from the waters of the estuary".

For estuaries that meet extensive coastal intertidal zones, the spatial extent of estuarine influence is often unclear. It is difficult to determine where the estuary fringe ends, and the non-estuarine coastal intertidal zone begins. For this assessment, the relevant fringing vegetation must somehow be divided from the coastal intertidal zone (or, in a few cases from extensive hind-dune marshlands which connect multiple estuaries).

This should be done using a buffer around the "permanently inundated" portion of the estuary, with the buffer distance 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. Such a buffer should only apply to estuaries with fringe boundaries that are ambiguous because they meet a coastal intertidal zone. These 21 estuaries are listed in the table below. All other estuaries have an obvious boundary at the coast, and do not need to be buffered.

The table shows the 'relative accumulated flow' for each estuary, and the buffer derived from this flow that should be used for each estuary. This 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 re-weighted so that the estuary which accumulated the least flow 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. This is the buffer shown in the Table.

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 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.

Estuary	Relative accumulated flow	Relative accumulated flow (log10)	Buffer (m)
Yallock Drain	2	1.29	25
Neils	8	3.42	68
Stockyard	31	5.71	114
Skeleton	36	5.93	119
Laverton	45	6.32	126
Lang Lang	90	7.46	149
Nine Mile	593	10.58	212
Yallock	671	10.78	217
Bennison	1,403	12.01	240
Bunyip	2,129	12.70	254
Warringine	3,405	13.48	270
Shady	3,485	13.52	270
Old Hat	4,960	14.10	282
Watsons	12,078	15.57	311
Agnes	16,968	16.14	323
Franklin	26,054	16.85	337
Tarra	44,223	17.73	355
Little	52,772	18.02	360
Albert	65,537	18.38	368
Merriman	68,319	18.45	369
Deep	74,128	18.58	372
Cardinia	74,133	18.58	372

8 Appendix 3: Potential indicators that were excluded

Several potential indicators were considered for inclusion, but ultimately rejected. These are listed below, with the reasons for their exclusion.

Plant species richness

Estuaries provide habitat for a large number of native plant species, which have inherent value as part of Victoria's biodiversity. Species richness measures the number of species that are present in a defined area, and most condition measures assume that high richness is preferred over low richness.

Using species richness to assess condition is possible. Indeed, both Habitat Hectares and IWC assess species richness, and the benchmarks specify the number of species expected to occur in each life-form group. Despite this, species richness was excluded from scoring here, since the experts did not favour its inclusion (See Appendix 1). The specific reasons for its exclusion are:

- Some of the most common estuarine fringing vegetation communities are inherently very species poor over quite large areas, and it is not clear that species richness is a relevant measure of condition in such cases (e.g. natural mangrove or Phragmites-dominated vegetation may support only 1 or 2 species over relatively large areas).
- A reliable assessment of richness requires a relatively large investment of time, because many species will be present at low levels, where their presence is not initially obvious. The IEC fringing vegetation metric is intended to be a rapid metric, and it species richness was considered too labour intensive to measure in a truly meaningful way (see below).
- The species count is expected to increase as the search area increases. Although the benchmarks provide an indication of expected species numbers, they do not provide a relationship between 'count' and 'area' that allows useful scoring in situation where patch areas vary from very large to very small.
- Apart from the dominants, quite a few estuarine species are relatively inconspicuous, and may only be encountered after extensive survey (e.g. Limonium australe, Triglochin species).

Absolute extent of estuary vegetation

Large patches of habitat are often preferred to small patches of habitat in conservation biology. Accordingly, Habitat Hectares penalizes small and fragmented sites (Parkes et al. 2003). This approach makes sense in situations where a continuous fabric of vegetation has been cut into fragments, and the value of these fragments must be compared. However, in the case of estuaries, which are inherently bounded and constrained by their geomorphological context, and their extent does not reflect their degree of degradation, only their identity. For this reason, 'extent' was excluded from the assessment.

Physical disturbance

Estuarine vegetation condition is often reduced by the direct effects of human activity, including vehicle and foot traffic in sensitive areas. The direct physical evidence of damage was excluded because much of its impacts are already scored through the loss of vegetation structure and exotic invasions (Indicators 2 and 3).

Landscape context of estuary vegetation

The idea of 'landscape context' expresses how well a site is integrated with or joined to other areas of relevant habitat. This concept is emphasized in 'Habitat Hectares', which rewards sites that are joined to, or in the vicinity of other areas of native vegetation (Parkes et al. 2003). IWC also considers landscape context, by considering the land-use within a radius of 250 m from the wetland boundary, and the 'nativeness' of buffering vegetation up to a 50 m radius from the wetland. The concept of 'landscape context' makes most sense in contexts where ecological processes are expected to operate across boundaries. This may include the movement of species within and between patches, or the operation of threats from boundaries into patches of habitat. In the case of estuaries, this model is of questionable value. Estuaries may be comparatively 'unlinked' to neighbouring patches of native vegetation, even under natural conditions, because their habitats are so different form their surrounds, and their ecological flows are so strongly linear. It is difficult to determine to what degree and in what directions estuaries are linked to their surrounds. Thus, meaningful scoring of an estuary's ecological context is extremely difficult, and prone to perversity.

Catchment condition

The idea of catchment condition is similar to landscape context, but is more explicitly related to the flow of resources and organisms into and through an estuary (Walker and Reuter 1996, Harris 2001). The IWC considers the land-use within a radius of 250 m from the wetland boundary, and the 'nativeness' of buffering vegetation up to a 50 m radius from the wetland. Although of obvious importance, catchment condition was excluded for three main reasons:

- The assessment of catchment condition may be best categorized as the assessment of the threats and pressures on an estuary, rather than a primary indicator of its current condition. In other words, the inclusion of catchment condition in a metric would anticipate and pre-judge the influence of upstream processes before they actually acted.
- Catchment condition is itself a complex concept, and would be relatively difficult to assess (although possible).
- Catchment condition influences all elements of an estuary, and if it were to be included in IEC its place should not be as a component of the 'fringing vegetation' assessment.

Extent to which the intertidal zone is able to retreat upland under sea level rise

Under sea level rise, coastal wetland vegetation communities will suffer one of three fates. They may be inundated and locally extirpated. They may be forced to retreat inland to sites of higher elevation. If they are capable of sufficient rates of sediment elevation, they may maintain themselves in their current position (Krauss et al. 2013; Rogers et al. 2016). There is evidence that these processes are already occurring in south eastern Australia (Prahalad et al. 2011). Estuaries that are bordered inland by extensive low-lying coastal plains may be able to accommodate the migration of wetland vegetation, while estuaries with steep sides may not. The local topographic context and the ability of the vegetation to trap sediment or accumulate below-ground biomass thus influences how 'resilient' estuarine vegetation communities are to change. This form of 'resilience' could be argued to be an element of condition, and the degree to which the intertidal zone can migrate could be assessed and scored. This approach was not taken, for reasons similar to those outlined above for the extent of the estuary: the ability to retreat relates to an estuary's inherent identity, not to its degree of degradation, nor is it related to management or the operation of threats.

High threat weeds

For any vegetation type, some exotic species invade far more rapidly and extensively than others, and different species are more or less able to exclude different native species. In other words, in a given system, some weeds are high threat, others are more-or-less benign. Habitat Hectares (Parkes et al. 2003) and IWC both consider sites with a given weed cover to be in worse condition if this cover is composed of high threat weeds. These weeds are identified on a list curated by DELWP. In the current context, the threat status of weeds was not considered when deriving a score. This decision was based on two main considerations:

- Scoring on the basis of which weed species is occupying space brings an unwanted element of pre-judgement to the scoring system, because the penalty incurred is based on an assumption of how weed species will behave in future; not on how much impact they have had.
- The distinction of high threat weeds requires the curation and publication of a list, which is an ongoing administrative burden. The distinction of high threat weeds may be controversial, or may not be clear until after a new weed has been present in a system for an extended period. If emerging weeds are to be added to the list, retrospective re-scoring would be required to allows scores to be comparable over time.

Structural habitat elements

The fringing vegetation of estuaries provides important habitat structures for the animals which inhabit the estuaries. These include hollows and roosts for birds and bats, and submerged shelter for fish (Hindell and Jenkins 2004, Nagelkerken et al. 2008). While acknowledged as important, these elements were not included here because of the great difficulty in detecting or reliably quantifying these elements, which may be cryptic or difficult to access. A direct measure of hollow abundance was excluded from habitat hectares for the same reasons (Parkes et al. 2003).

Distinction between the 'perimeter zone' and the remainder of the fringe

The first version of this assessment produced separate scores for the perimeter zone, defined as a 5 m strip along the edge of the permanently inundated zone, and the remainder of the fringe. This distinction was made to allow estuaries to be assessed only by boat, during field work for the submerged aquatic indicators (the perimeter), and, less frequently, for the remainder of the fringe. The concept was discarded for several reasons, including the difficulty of defining the perimeter strip, and the fact that many estuaries can be more readily visited from the terrestrial periphery than from the water.