Changes in the area of coastal marsh in Victoria since the mid 19th century

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Abstract: European settlement in Australia has always been concentrated along or close to the coast. As a consequence, saltmarshes, mangroves and other coastal marshes have experienced a long history of modification and destruction. Depletion statistics are available for many coastal marshes in the Northern Hemisphere and, in Australia, for parts of New South Wales and Queensland. There are no equivalent State-wide data for Victoria. Using a suite of historical information, including extensive use of early surveyors' maps, we aimed to provide a consistent view of the change in the extent of coastal marshes since European colonization in Victoria (i.e. the mid-19th century). Notwithstanding the difficulties of interpretation, we estimate that prior to European colonization Victoria supported approximately 346–421 km^2 of coastal marsh, of which approximately 80–95% remains. Although a simplistic interpretation suggests a net loss of 5–20% in wetland area over this time period, it is clear that some parts of the coast have experienced relatively little change since the mid 19th century whereas others have been severely depleted and, in a few sectors, there may have been an expansion of coastal marsh. The situation with the Gippsland Lakes is complex, and according to the method used to interpret the original data sources there has either been a substantial increase or a loss of up to 35% in wetland area around Lake Wellington. The largest absolute losses have probably been of EVC 140 Mangrove Shrubland and of coastal saltmarsh dominated by *Tecticornia* spp. Parts of the coast where significant losses have occurred include the Lonsdale Lakes, western shore of Port Phillip Bay, Anderson Inlet, Shallow Inlet, Powlett-Kilcunda, Corner Inlet and Nooramunga, and possibly Lake Wellington. With the exception of the Lonsdale Lakes, all these areas are situated along the Gippsland coast. Changes to coastal marshes have not stopped and are unlikely to cease in the near future. The destruction of coastal marshes for industrial development remains an ongoing threat in many regions (e.g. in Western Port) and is likely to be compounded by climate change and, in particular, sea-level rise.

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Introduction

Because of their position along the coast where land is acquired for human settlement, saltmarshes, mangroves and other coastal wetlands have experienced a long history of modification and destruction. Gedan *et al*. (2009, page 117) concluded that 'since the Middle Ages, humans have manipulated saltmarshes at a grand scale, altering species composition, distribution, and ecosystem function'. In some cases, such as across much of northern Europe, coastal saltmarshes have been used for agricultural purposes since at least the 17th century and possibly even as early as the 13th century (Adam 1990, French 1997). In other cases, it is known that physiographic changes to estuaries since pre-Roman times have had marked impacts on the distribution of coastal marshes (Steers 1977). The European experience was broadly repeated in North America: Gedan & Silliman (2009) estimated that approximately 40% of coastal saltmarsh has been lost from the North Atlantic coast and over 90% from the Pacific coast of North America since European colonization (baseline dates range from 1609 to 1893). The greatest early losses probably arose as a result of the direct and wholescale conversion of marshes for agricultural or urban uses or for the salt industry, whereas over recent decades a suite of other indirect factors have become responsible, including subtle alterations to wetland hydrology and nutrient loading, as well as the introduction of introduced species, both plant and animal (e.g. see Morris *et al*. 2004, Silliman *et al*. 2005, Jefferies *et al*. 2006).

Because of the country's more recent colonization by Europeans, Australian coastal marshes do not share the centuries-old history of large-scale modification that characterizes so many Northern Hemisphere systems. Nevertheless, almost all coastal areas of south-eastern Australia have experienced some degree of alienation and habitat modification or destruction over the past 150–200 years. In the Koo Wee Rup Swamp on the northern shore of Western Port (Victoria), for example, large areas of open wetland and paperbark swamp (*Melaleuca ericifolia*) were 'reclaimed' for agriculture in the late 19th and early 20th century, as described enthusiastically by East (1935) and by Roberts (1985); see Yugovic & Mitchell (2006) for a detailed analysis of changes in this region since European colonization. Similarly, Bird (1980*a*, 1980*b*) reported that, in places, the mangrove fringe of Western Port had been reduced markedly by clearing, infilling, drainage and die-back. Changes to the shoreline shown in surveys of the mid 19th century were evident by 1939 (Bird 1980*a*, 1980*b*) and have continued apace since then. A boat channel, for example, was cut into mangroves and saltmarsh in 1967 at Yaringa (Bird 1971), and even more extensive port, marine and industrial developments have taken place over the past two decades and, indeed, are reputed to be planned for the near future for this mangrove- and saltmarsh-fringed coastal embayment.

In the late 19th Century, Victorian mangroves and coastal saltmarsh plants were heavily exploited for their soda-ash content (Bird 1978, 1981). Since tallow was abundant (because of the large number of sheep) but soap relatively scarce, many types of native vegetation were burnt to yield the ash needed for soap-making (Adam 1990). Halophytic plants were an excellent source of ash, and Carr & Carr (1981) and Whinray (1981) noted that *Tecticornia arbuscula*, *Sarcocornia quinqueflora*, *Atriplex cinerea* and *Rhagodia candolleana* (the latter being a common coastal species which is rare and only opportunistic in saltmarshes: Geoff Carr, pers. comm) were used in the same way. Mangroves, however, were the main source of ash, and their utilization to generate barilla was so intense that Bird (1978, 1981) argued that clearing mangroves for ash production has had long-term impacts on their distribution in Victoria. Indeed, in his review of the natural history of French Island (in Western Port), Lacey (2008) noted that the first Europeans recorded as living on the island (~1843/1844) were engaged in burning mangroves to produce barilla for soap-making.

Large expanses of coastal saltmarsh were also alienated for salt production in the 19th century between Melbourne and Geelong, on the western shores of Port Phillip Bay and Corio Bay, where as a result of low rainfall (~600 mm per year) evaporation greatly exceeds precipitation. Shell-grit mining has been undertaken in other coastal saltmarshes around Victoria, mostly to produce lime, for road building, and as source of calcium carbonate for the poultry industry. Much of this mining has occurred in areas adjacent to or supporting saltmarsh, predominantly on the western shores of Port Phillip Bay and Corio Bay from Melbourne to Point Lonsdale, but also in the Point Lonsdale–Collandina area. Moreover, Laegdsgaard (2006) noted that many Australian saltmarshes, especially in New South Wales, were on private land and subject to stock grazing. This is certainly the case also for Victoria, where coastal saltmarsh is routinely grazed by cattle (particularly in western Victoria and Gippsland) and sheep (e.g. around Port Phillip Bay), as well as being grazed by introduced animals such as feral deer and goats (e.g. on French Island).

Finally, the exotic and invasive *Spartina* (*Spartina anglica* and *Spartina* x *townsendii*) is present in a number of Victorian saltmarshes and other coastal areas. The first documented introduction of *Spartina* to Australia was a planting in Corner Inlet, probably in the 1920s, by Professor AJ Ewart from the University of Melbourne (Boston 1981). Williamson (1996) provided an overview of *Spartina* introductions into Victoria. As reported by Bird & Boston (1968), early plantings of *Spartina* occurred at Lake Connewarre, the Bass River, Corio Bay, Anderson Inlet, and several locations in Corner Inlet in the 1920s and 1930s. Although most of the original introductions were unsuccessful, in some parts of Victoria *Spartina* did expand rapidly. The spread of *Spartina* through Anderson Inlet, for example, started to be noticed in the 1980s and the Department of Conservation and Natural Resources began to investigate it in 1991 (Blood 1996, Williamson 1996). Mapping in 1993 showed there were 150–280 ha of *Spartina* in Victoria, with most in Anderson Inlet (108 ha confirmed, 130 ha suspected), Corner Inlet (42 ha) and small infestations in Shallow Inlet, Western Port and the Barwon River (Williamson 1996).

Saintilan & Williams (2000) reviewed the records of saltmarsh loss in eastern Australia and, based on 28 surveys employing historical aerial photographs, showed that there had been a widespread loss since the 1940s–1950s. Reported losses were as high as 100% for Weeney Bay (part of Botany Bay, New South Wales, from 1950–1994) and 67% for the Hunter River estuary (excluding Hexham) from 1954–1994. Harty & Cheng (2003) reported a loss of 78% of saltmarshes in Brisbane Water, near Gosford, New South Wales, between 1954 and 1995. The studies reviewed by Saintilan & Williams (2000) were overwhelmingly taken from Queensland and New South Wales, and the sole Victorian study was that by Vanderzee (1988), who reported extensive – but unquantified – loss of coastal saltmarsh in the Corner Inlet region.

Ross (2000) reviewed changes to the distribution of mangrove and coastal saltmarsh around parts of Western Port, using the 1842 maps of the surveyor George Douglas Smythe as a baseline. She found evidence of clearing of mangroves in particular (for boat access and to burn for barilla production) but did not make quantitative estimates as to the magnitude of wetland loss or expansion. In one of the few quantitative studies undertaken of the Victorian coast, Ghent (2004) compared past and present distributions of coastal saltmarsh in Port Phillip Bay, and concluded that ~65% of pre-European saltmarsh had been lost, mostly before 1978.

Saintilan & Rogers (2001) surveyed mangroves and coastal saltmarsh around Quail Island (Western Port) and found an increase of 32% over the period 1973–1999. Gullan (2008) estimated that about 30% of Victorian coastal saltmarsh had been permanently cleared for coastal or marine development.

It is the case, therefore, that we have little or no quantitative understanding of how coastal marshes across Victoria as a whole have changed since European colonization. This situation is partly the result of regional studies employing different methods or concentrating on areas of different scale. State-wide figures cannot be extrapolated from isolated studies of given localities, as different places with different histories may have experienced locally large losses, expansions or remarkable stability. These local differences relate to idiosyncratic site-specific histories, and may involve natural geomorphological changes or human-induced changes of many kinds.

The current investigation aims to provide a consistent view of the change in the extent of coastal marshes in Victoria since European colonization (i.e. the mid-19th century).

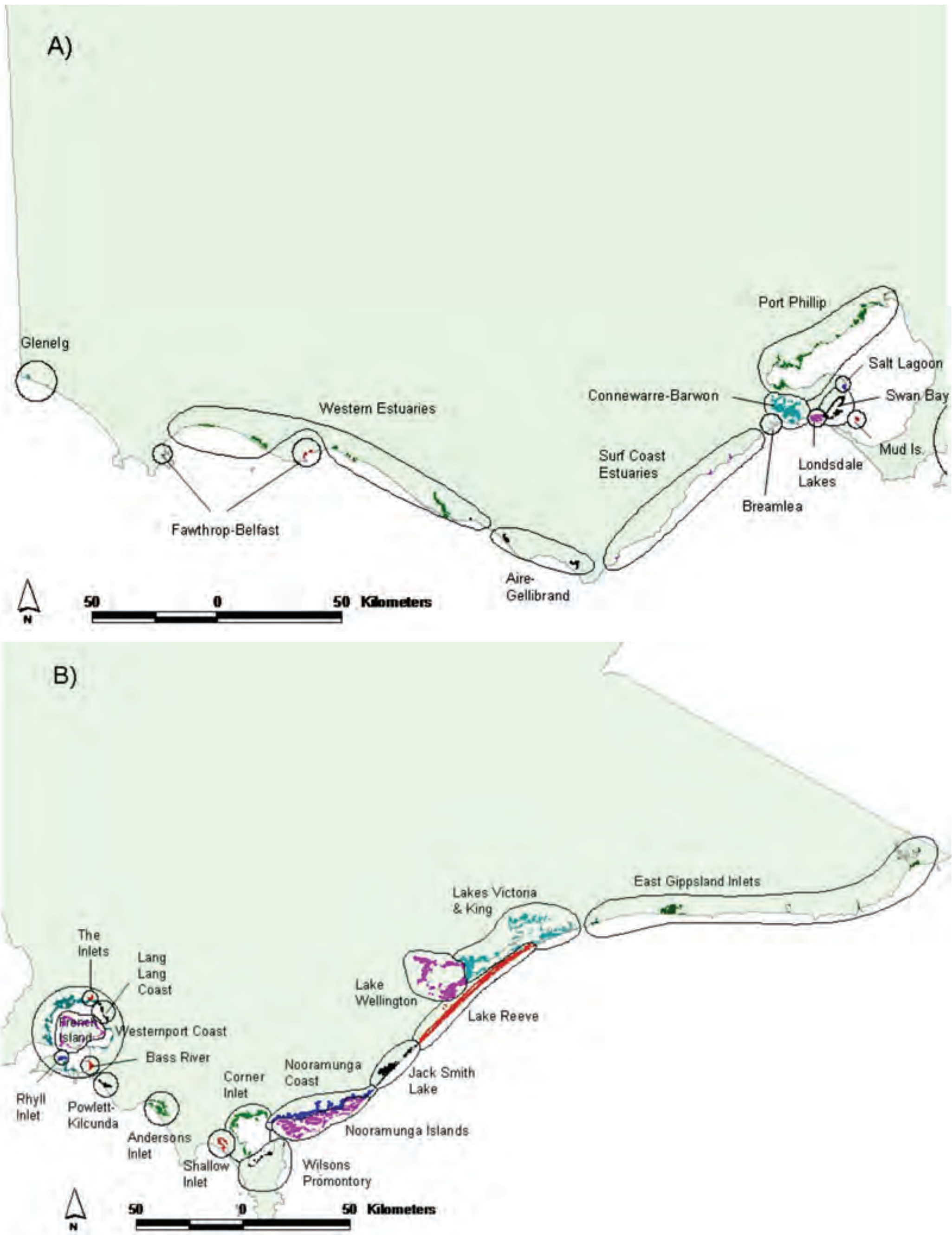

Fig. 1. Division of the Victorian coast into sectors for the purposes of calculting losses or gains in each region. A) shows western and central Victoria; B) shows eastern Victoria.

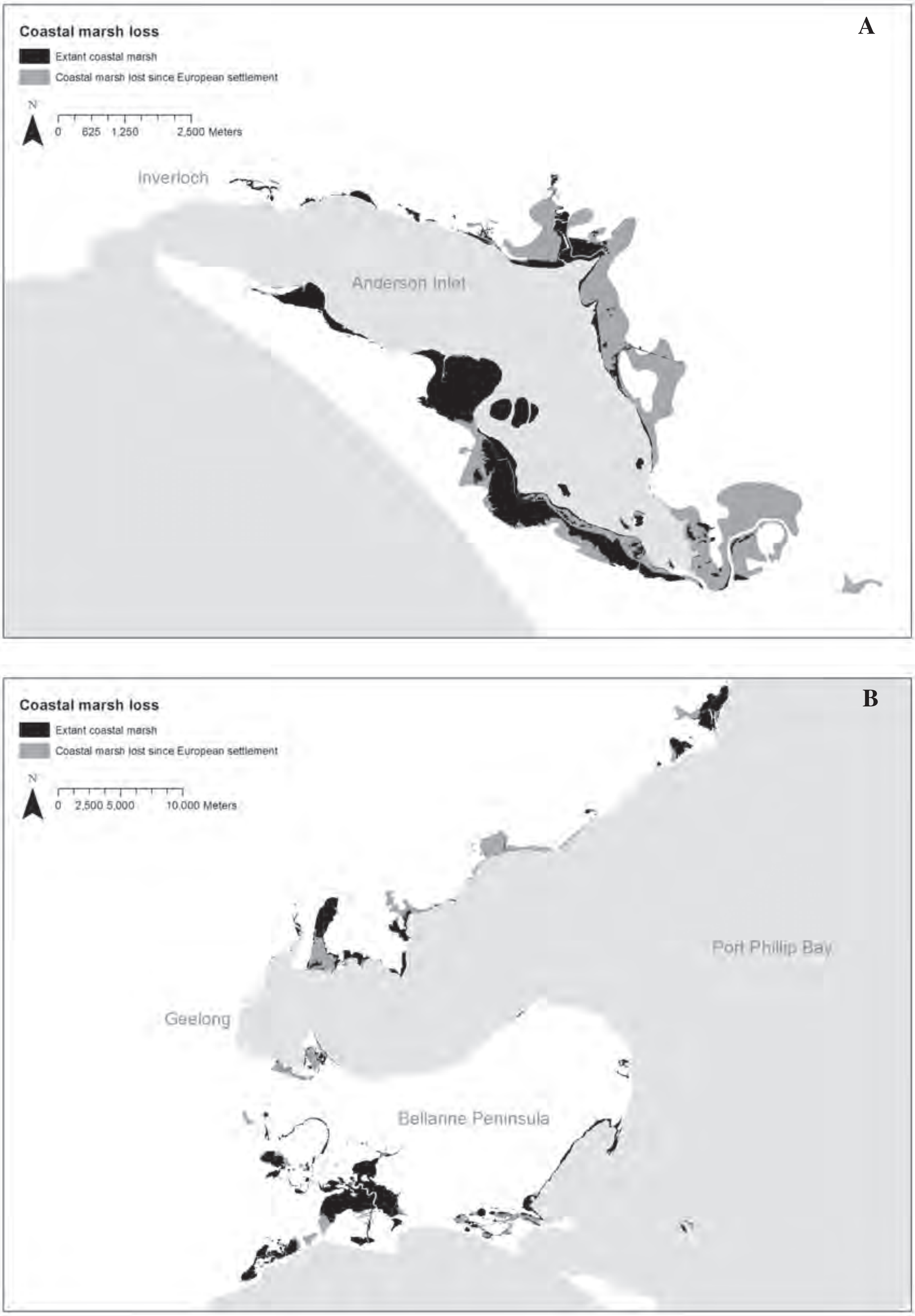

Fig. 2. Examples of the extent of loss of coastal marsh in Victoria. A) shows Anderson Inlet; B) shows the western shore of Port Phillip Bay and the Bellarine Peninsula. The black shading shows current marsh distributions; middle grey shading shows areas of marsh lost since European colonization; light grey shadings are open water; white is terrestrial land.

It elaborates on work undertaken as part of the Victorian Saltmarsh Study (2011), which showed that the present-day area of coastal saltmarsh and estuarine wetland (saline coastal wetlands dominated by halophytic shrubs, herbs, grasses or sedges) in Victoria was 224 km^2 and that of mangroves was 52 km^2. The specific aim of our investigation was to quantify the loss of coastal marshes, including mangroves, saltmarsh and estuarine wetland, since European colonization.

Methods

Information sources

We used three approaches to quantify changes in the area of coastal wetlands across Victoria since European colonization. The first was to interrogate coastal maps prepared in the mid 19th century, mostly by surveyors and geologists. In some places, early surveyors' plans show saltmarsh (often referred to as 'samphire') and mangrove patches quite clearly. In other cases, low water, high water and the spring-tide maximum are shown as lines. On some plans, wetlands are shown and labelled 'salt' or 'fresh', thus allowing some assumptions to be made as to the plant assemblages or wetland types that formerly occupied the site. Other maps show unannotated wetlands that are ambiguous, in which case we used current-day information to infer the likely wetland type. We searched for useful early maps using the catalogues of the National Library of Australia and the State Library of Victoria, along with sections of the Public Records Office microfiche collection. Sources are shown in Table 1.

Second, we used on-ground interpretation. As part of the preparation of the State-wide saltmarsh inventory, we (and others) undertook extensive ground-truthing of oblique aerial photographs (Victorian Saltmarsh Study 2011). Where field teams noted evidence of wetland infilling or modification, such evidence was recorded and, where possible, the likely former extent of the wetland marked on the aerial images. Although this was sometimes a simple task, the interpretation is nevertheless often confusing, particularly where no vestige of the former high-tide boundary remained or where obvious palaeo-coastal features from periods much earlier than European colonization (e.g. from the Holocene maximum: see Pirazzoli & Pluet 1991) could be mistaken for more recent shorelines.

Third, we used remote-interpretation tools directly. Where there were no useful early maps or sites were not visited in the field, aerial photographs were re-viewed to check for clues about the prior vegetation and wetland extent. Evidence of channels or levees used to drain low-lying coastal plains, for example, was taken as evidence of former saltmarsh vegetation. We also used elevation data to check that our view of pre-European saltmarsh only included low-lying areas. As we did not have access to LiDAR elevation data at the time for the entire Victorian coast, we used the freely-available elevation data from the NASA Endeavour 'Shuttle Radar Topography Mission' 2000 (see Farr *et al*. 2007). Remote-sensing tools were particularly helpful in the Corner Inlet and Nooramunga areas, where the historic record is not detailed and physical access is difficult. (Note that since this study was undertaken, LiDAR data have become available for the entire Victorian coastline and they should prove to be valuable for future investigations into wetland dynamics and sensitivity to anthropogenic change.)

Vegetation units and wetland types

In Victoria the system used for classifying and mapping native vegetation is based on Ecological Vegetation Classes (EVCs), which are defined as one or a number of floristic and structural types that appear to be associated with a recognizable environmental niche and can be characterized

Fig. 3. Flowerhead of Native Sea Lavender, *Limonium australe*, a saltmarsh plant listed as Vulnerable in Victoria.

Fig. 4. Creeping Brookweed, *Samolus repens*, a common herb in Victorian coastal saltmarsh.

Table 1. Summary of historic sources used to infer pre-European extent of coastal marshes in Vicotria. Maps are listed chronologically. When the map or source material is undated (or date illegible), we refer to the item as 'undated', unless there is an approximate or apparent date of production (e.g. in marginal annotations), in which case we use the abbreviation 'c.'. Where the material is untitled, we provide a brief description of the map in square brackets. The name of the public institution holding the map is abbreviated as follows: Public Records Office of Victoria: PROV; National Library of Australia: NLA. The microfiche sets of the Public Records Office of Victoria are abbreviated as follows: Gippsland Rivers: GR; Coastal Surveys: CS; Special Surveys: SS.

Date	Surveyor	Title [or description]	Source
1837	Russell R	Map shewing the site of Melbourne and the position of the huts & buildings previous to the foundation of the township by Sir Richard Bourke in 1837.	NLA MAP RM 1288
1840	Myers CI	Rough sketch of part of the district of Gipps Land based on Mr Ass. Surveyor Townsends' chain measurement from Port Albert to Omeo shewing the positions and area of the several stations.	PROV GR24
1841	Anon.	Survey of part of the Parish of Moolap, 1841, suburban lots.	PROV [location unknown]
1842	Anon.	Plan of the town of Alberton on the River Albert.	PROV S3A
1842	Smythe GD (a)	Sheet No. 5 of Western Port Coast	PROV CS69
1842	Smythe GD (b)	Survey of the islands of Western Port	PROV CS16
1842	Smythe GD (c)	Survey of the eastern coast of Western Port Sheet No 6.	PROV CS15A
1842	Smythe GD (d)	Survey of the N west coast of Western Port from Toorndeeck to Baangring	PROV [location unknown]
c.1842	Anon.	[untitled. Map of Alberton area]	PROV SS1
1843	Anon.	Survey of the proposed town reserve at Port Fairy.	PROV CS37A
1843	Hoddle R	Survey of part of the Parish of Paywit County of Grant.	PROV SP18
1843	Myers CI	Plan of Port Fairy shewing the position of Mr Atkinson's special survey.	PROV SS8
1843	Smythe GD	special surveys at Port Albert and some portions for sale on the River Tarra.	PROV CS4
c.1843	Anon.	[untitled. Map of Port Fairy area]	PROV SS8
1847	Smythe GD	Survey of the rivers and creeks from the Barwon Heads to Point Roadknight.	PROV CS30B
c.1847	Smythe GD	Survey of the coast from Cape Patterson to Cape Liptrap with rivers, creeks, lakes, marshes, swamps, scrubs, plains and ranges within one days work of coast.	PROV CS14
1848	Smythe GD	Plan of part of the Gipps Land District from Cape Patterson to Shallow Inlet and from Cape Wellington to Shallow Inlet West.	PROV CS43
1849	Wright	Plan of Corner Inlet Gippsland shhewing the town of Alberton.	PROV CS52
1849	Wilkinson J	Survey of the northern shore of Lake Wellington, The Straits, Tom's Creek etc.	PROV CS51
1849	Wilkinson J	Survey of the Nicholson and part of the Tambo Rivers.	PROV GR9
c1849	Wilkinson J	Survey of the Macarthur or Mitchell River from Lake King to the ford at Lindenow and Lake Victoria from Jones' Backwater to Storm Point.	PROV GR6A
1850	Anon.	Plan of the Town of Belfast, Port Fairy.	PROV SB3
1850	Garrard & Shaw	Map of the town and suburbs of Geelong comprising the lands in the parishes of Gheringhap, Moorpanyal, Barrabool, Duneed, Moolap, Bellerine & Paywit: together with the positions of the bar and the proposed improvements.	NLA MAP RM 1963
1853	Barrow J	Survey of Lady Bay, Warrnambool.	PROV CS35B
1853	Christie	[untitled. Map of Melbourne]	NLA MAP RM 3473
1854	Barrow J	Warrnambool shewing a plan to prevent the accumulation of sand in Lady Bay.	PROV CS98
1855	Byerley J	Subdivision of sections in the parish of Connewarre County of Grant Part 4.	NLA MAP NK 2456/217
1855	Lees EH	Plans of Wingan River, travserse from inlet northwards, County of Croajingalong.	PROV GR53
1855	Watson	Country lands in the parishes of Codrington and Eumerella, Counties of Normanby and Villiers.	NLA MAP NK 2456/216
1859	Ross R	Corio Harbour, Geelong Bay	PROV CS29A
1862	Daintree R & Ross JL (a)	Geological Survey of Victoria No. 29.	NLA MAp RM 2335/29 Tile 1a
1862	Daintree R & Ross JL (b)	Geological Survey of Victoria No. 32.	NLA MAP RM 2335/23 Tile 1b
1863	Daintree R	Geological Survey of Victoria No.23	NLA MAP RM 2335/23 Tile a1
1863	Daintree R & Shepherd R (a)	Geological Survey of Victoria No. 23..	NLA MAP RM 2335/23 Tile b2
1863	Daintree R & Shepherd R (a)	Geological Survey of Victoria No. 29.	NLA MAP RM 2335/29 Tile a2
1863	Daintree R, Wilkinson CS & Shepherd R	Geological Survey of Victoria No. 29	NLA MAP RM 2335/29 Tile a3

1864	Cox HL	Port Phillip	NLA MAP RM 1696
1866	Bailliere FF	County of Mornington.	NLA MAp RaA 16 (Pl. 13)
1869	Stonley HJ (a)	Portland Bay	PROV CS38
1869	Stanley HJ (b)	Coast from Cape Wollamai to Cape Liptrap	PROV CS14
1869	Stonley HJ (c)	Venus Bay and Anderson's Inlet	PROV CS62A
1874	Cox HL & Stanley HJ	Entrance to Port Phillip including the banks and channels.	NLA MAP RM 2379
1880	Noone J	Cocooc, County of Grant	NLA MAP RM 2741/287
1880	Noone J	Murtcaim, County of Grant	NLA MAP RM 2741/310
1896	Goldsmith L & McGauran TF	Deutgam, County of Bourke	NLA MAP RM 3013
undated	Anon. (a)	[untitled.Map of Andersons Inlet and Cape Liptrap	PROV CS43D
undated	Anon. (b)	[untitled. Map of Alberton area]	PROV CS55
undated	Anon. (c)	[untitled. Map of Alberton area]	PROV SS1
undated	Anon. (d)	Plan of survey of sea coast from Lake Reeve to Snowy River with part of Lake Victoria	PROV CS3
undated	Anon. (e)	[untitled. Map of Gippsland Lakes]	PROV CS42
undated	Anon. (f)	Snowy River Coastal Survey 34	PROV GR32
undated	Barrow J	Plan shewing the mouth of the River Moyne at Belfast	PROV CS97
undated	Proeschel F	Map of Melbourne and suburbs	NLA MAP RM F878
undated	Smythe GD (a)	Survey of the coast from Cape Liptrap to Shoal Inlet and one day works inland with the line to Corner Inlet, Mr Townsend's Survey.	PROV CS14C
undated	Smyhe GD (b)	Survey of Shoal Inlet and Part of the Ninety Mile Beach to Mr Surveyor Townsends marked tree at the mouth of the Tambo River.	PROV CS8
undated	Smythe GD (c)	Plan of coast survey from Stas. C to D. Part of Lake Victoria, Lake Reeve, Raymond Island, Lake King to the mouth of the Mitchell and Tambo Rivers.	PROV CS4 & CS5
undated	Smythe GD (d)	Survey of part of the Ninety Mile Beach with rivers, creeks, lakes, marshes, roads and stations within one days work of the sea-coast.	PROV CS4 & CS5
undated	Smythe GD (e)	Survey of Coast from Merriman's Creek to Lake Reeve	PROV CS6
undated	Urquart WS	Rough sketch from- plan of the Merri River shewing the situation of the last special survey selected by Mr Wm Rutledge.	PROV SS6B

by their adaptive responses to ecological processes that operate at the landscape scale. The EVC approach to vegetation classification therefore uses floristic and structural criteria, combined with geographic information on niches and distributions (Oates & Taranto 2001, Department of Natural Resources and Environment 2002).

The different methods for determining pre-European vegetation patterns varied in their ability to resolve different vegetation and wetland types, but generally were poor. Because of this limitation, we chose to represent only two mapping units:

- Mangroves. All vegetation anywhere in Victoria where *Avicennia marina* occurred, as per EVC 140 Mangrove Shrubland (Department of Sustainability and Environment 2009).
- Other Coastal Marsh. This unit includes all intertidal wetlands not dominated by *Avicennia marina*. For the purposes of our analysis, it includes saltmarshes dominated by succulent chenopods, sedges (e.g. *Gahnia trifida*), rushes (*Juncus kraussii*), grasses (e.g. *Distichlis distichophylla*) and the herb *Wilsonia* spp. (Some of the dominant species occur widely near the coast, so only those areas that were sometimes inundated by saline water were included). In many estuaries it is difficult to determine where tidally inundated areas meet river waters. As a simple solution, we included all estuarine marshy areas currently dominated by *Juncus kraussii* and excluded all areas dominated by *Phragmites*, *Typha*, *Cladium*, *Bolboschoenus*, *Schoenoplectus* or any woody species. Brine pools vegetated by plants that grow ephemerally after inundation (e.g. *Ruppia* spp., *Lepilaena* spp.) were included if they were surrounded by coastal saltmarsh. Given the above interpretation, our circumscription corresponds to EVC 9 Coastal Saltmarsh Aggregate, EVC 10 Estuarine Wetland, EVC 196 Seasonally Inundated Sub-saline Herbland and, where occurring within a marsh, EVC 842 Saline Aquatic Meadow and bare ground.

To reflect the uncertainty about which vegetation types grew where, the general term 'coastal marsh' is used below to refer to relevant units where their type is not precisely known. Table 2 shows a summary of the different vegetation units, classified according to EVCs.

Division of coast into sectors

For the purposes of description and reporting, we divided the coast into 30 sectors that represent discreet areas with relatively homogeneous geomorphology, rainfall and land-use. They are not all of the same size, and some contain much more wetland than others. Whilst most sectors are nested within a single bioregion, some straddle two (e.g. Breamlea). The sectors are shown in Figure 1 and briefly described in Table 3.

Data manipulation and map generation

The information from the diverse information sources was used to compile a map of the likely pre-European distribution of relevant coastal wetlands across Victoria within each of the 30 coastal sectors. The distribution of wetlands was prepared as a digital map dataset as a series of spatially referenced polygons. All polygons were drawn by hand, using Arcview 3.2 (ESRI), and traced directly from historical sources or current-day aerial photographs. A stream digitiser was used with a sensitive screen and stylus (Minnesota Department of Natural Resources 2000; using a Wacom tablet screen) to allow fluid outlines to be drawn. This instrumentation allowed direct tracing of the shapes on the screen in the same manner as has been used traditionally with a pencil and tracing paper over an annotated map image. The polygons were attributed with a series of fields describing their vegetation type, etc.

In cases where the early cartography was good and vegetation patterns relatively simple, polygons were captured using transparencies traced from the historic plan placed over the screen. Where the original plans were distorted in relation to our maps, for example due to cartographic errors or different projections, the historic plans were captured digitally and geo-rectified to align in space with our map data. This was done by digitally stretching the images against known reference points, using the 'ImageWarp' software available as an extension to Arcview 3.2 (ImageWarp version 2.0, 1999). The rectified images were then used as templates in the same way as the aerial photographs. In cases where the information was insufficient to geo-rectify the image or where the level of accuracy in the original product was very poor, we interpreted the historic information 'by eye'. In

Table 2: Range of estuarine vegetation types referred to in the study, classified by Ecological Vegetation Class (EVC).

EVC	EVC name	Characterization	Indicator species
10	Estuarine Wetland	Rushland/sedgeland vegetation, variously with component of small halophytic herbs, occurring in coastal areas where freshwater flows augment otherwise saline environments.	*Juncus kraussii*, occasionally with *Phragmites australis* or species of Cyperaceae.
842	Saline Aquatic Meadow	Submerged ephemeral or perennial herbland of slender monocots, occurring in brackish to saline water bodies subject or not to dry periods. The vegetation is characteristically extremely species-poor, consisting of one or more species of *Lepilaena* and/or *Ruppia*.	Variously *Ruppia megacarpa*, *Ruppia polycarpa*, *Lepilaena* spp. (e.g. *L. preissii*, *L. bilocularis*, *L. cylindrocarpa*).
140	Mangrove Shrubland	Extremely species-poor shrubland vegetation of inter-tidal zone, dominated by mangroves.	Characteristically occurs as mono-specific stands of *Avicennia marina*. In some stands, species from adjacent Coastal Saltmarsh or Seagrass Meadow also present.
196	Seasonally Inundated Sub-saline Herbland	Very species-poor low herbland of seasonal saline wetland within relicts of former tidal lagoons, dominated by *Wilsonia* spp.	*Wilsonia humilis* sometimes with *W. backhousei* and/or *W. rotundifolia*.
952	Estuarine Reedbed	Vegetation dominated by tall reeds (usually 2-3 m or more in height), in association with a sparse ground-layer of salt tolerant herbs. Distinguished from Estuarine Wetland by the vigour and total dominance of reeds, and from Tall Marsh by the presence of halophytes.	*Phragmites australis*, with associated species variously including *Samolus repens*, *Juncus kraussii*, *Triglochin striatum*, *Bolboschoenus caldwellii* and *Suaeda australis*.
953	Estuarine Scrub	Shrubland to scrub of myrtaceous shrub species of sub-saline habitat, occurring in association with ground-layer including halophytic herbs.	*Melaleuca ericifolia* (in eastern Victoria), with other *Melaleuca* spp. (e.g. *Melaleuca lanceolata*, *Melaleuca gibbosa*) or *Leptospermum lanigerum* in marginal sites in western Victoria. Gound-layer includes *Samolus repens*, *Triglochin striata* and *Selliera radicans*, variously with *Sarcocornia quinqueflora*, *Gahnia filum*, *Poa poiformis*, *Juncus kraussii*, *Disphyma crassifolium*, *Distichlis distichophylla*.

Table 3: Division of the Victorian coast into sectors for the purposes of calculting losses or gains in each region. Rainfall is approximate (to the nearest 100 mm) and refers to the immediate area not the entire catchment. The Bioregion names are abbreviated as per Department of Sustainability and Environment: Brid (Bridgewater); VVP (Victorian Volcanic Plain); WaP (Warrnambool Plain); OtP (Otway Plain); GipP (Gippsland Plain); WPro (Wilsons Promontory) and EGL (East Gippsland Lowlands).

Sector	Geomorphic context	Major adjacent land-uses	Bioregion	Rainfall (mm)
Glenelg	Estuary, limestone and calcareous barrier system.	Native vegetation, Agriculture, Plantation	Brid	800
Fawthrop-Belfast	Estuaries, lagoons with prominent flood-tide deltas, channelized openings, basaltic lowlands and barrier and dune systems.	Agricultural, Urban	VVP WaP	700
Western estuaries	Estuaries, subdued hinterland, barrier and dune systems.	Agricultural	WaP	700
Aire-Gellibrand	Large estuarine floodplains, steep hinterland and barrier systems.	Native vegetation Agricultural	OtP WaP	1000
Surf-coast estuaries	Small coastal floodplains, barrier systems, steep hinterland.	Native vegetation Agriculture, Urban	OtP	700
Breamlea	Estuary with barrier system, sand and silt deposits adjoining basalt.	Agricultural	OtP (VVP)	600
Connewarre-Barwon	Large estuarine floodplain, prominent flood-tide delta, sand and silt deposits, barrier spit, surrounding geology diverse.	Agricultural, Urban	OtP (VVP)	600
Lonsdale Lakes	Saline lakes isolated from ocean by complex sand and silt deposits, limestone.	Agricultural , Urban	OtP	700
Salt Lagoon	Saline lake isolated from the ocean.	Agricultural , Urban	OtP	700
Swan Bay	Embayment, sheltered by series of sand spits.	Agricultural , Urban	OtP	700
Mud Islands	Sand and shell-grit shoals, anchored on calcarenite.	None / Ocean Native vegetation	NA	700
Port Phillip	Coast of large embayment, largely low-relief basaltic hinterland.	Water treatment Agricultural, Urban Industrial	VVP OtP	600
The Inlets	Partly channelized outflow of drained swamp, tidal channels from sheltered coast of embayment	Agricultural	GipP	800
Western Port	Low-energy coast of large embayment, minor estuaries, large tidal range, extensive mudflats.	Agricultural, Urban Native vegetation	GipP	800
French Island	Coast of large island within Western Port, mostly sandy deposits, large tidal range.	Native vegetation Agricultural	GipP	800
Rhyll Inlet	Sheltered embayment behind sand spit.	Urban, Agricultural	GipP	800
Lang Lang coast	Cliffed and eroding coast.	Agricultural	GipP	800
Bass River	Large floodplain on Western Port coast.	Agricultural	GipP	800
Powlett-Kilcunda	Small estuaries.	Agricultural	GipP	800
Anderson Inlet	Shallow, sheltered inlet behind barrier, estuarine input.	Agricultural, Native vegetation, Urban	GipP	800
Shallow Inlet	Shallow, sheltered tidal inlet behind barrier.	Agricultural	GipP	800
Wilsons Promontory	Sheltered portions of coast.	Native vegetation	WPro	900
Corner Inlet	Sheltered coast, geology various, minor estuaries, extensive sand- and mud-flats.	Agricultural, Urban Native vegetation	GipP	900
Nooramunga coast	Sheltered coast opposite Nooramunga Islands, geology various, minor estuaries, extensive sand- and mud-flats.	Agricultural, Urban Native vegetation	GipP	800
Nooramunga islands	Complex of quartz sand barrier deposits forming sheltered inlets, extensive sand- and mud-flats.	Native vegetation Agricultural	GipP	800
Jack Smith Lake	Lake separated from ocean by sand barrier.	Agricultural	GipP	700
Lake Reeve	Saline lake system separated from ocean by sand barriers. Bordered by complex system of contraction ridges.	Native vegetation Agricultural, Urban	GipP	700
Lake Wellington	Coastal lagoon separated from ocean by large sand barriers.	Agricultural Native vegetation	GipP	700
Lakes Victoria and King	Coastal lagoons separated from ocean by large sand barriers.	Agricultural, Urban Native vegetation	GipP	700
East Gippsland inlets	Inlets, barrier-built lagoons and estuaries.	Native vegetation	EGL	900

some cases the different pieces of evidence were at variance. Multiple historic plans, and the evidence visible on the aerial imagery do not always tell precisely the same story and in all such cases a subjective compromise was made.

Calculating depletion statistics

Calculating accurate depletion statistics is complicated by the different resolution of the current and 19th century maps. We excluded areas of bare ground, brine pools and other minor inlying patches of non-saltmarsh vegetation generated by the Victorian Saltmarsh Study (2011), as we could not predict the distribution of these inliers on a suitably fine scale in the pre-European distribution map. Thus, we compared the pre-European area of coastal marsh to an increased current saltmarsh total that included these inlying areas; even so, the inflation factor was, on average, only 1.1. In the absence of other information, we assumed also that the relative proportions of ECV 10 Estuarine Wetland and EVC 9 Coastal Saltmarsh Aggregate remained constant during any process of historical depletion. As our study was undertaken at a State-wide scale using historic plans of limited accuracy, we could not capture all the very small changes that had occurred. Some of the changes found in other local studies using different techniques would be barely detectable at our scale (e.g. Vanderzee 1988, Saintilan & Rogers 2001). Small changes to the sea-ward mangrove fringe are particularly difficult to detect from our sources.

Results

Table 4 shows the estimated area of mangroves and other coastal marshes before European colonization ('pre-1750 area') and the present-day area for various sectors of the Victorian coast. The degree of retention is shown also for the two marsh types in each of the sectors. Because the historic resources that were available generally provided little or no information about non-mangrove coastal marshes, it was necessary to combine all of the non-mangrove wetland types into one group, called Other Coastal Marsh (Table 4). In the original sources these diverse wetland types were often labelled with an imprecise array of labels, such as 'salt', 'samphire' or 'saltmarsh'.

The Gippsland Lakes area presented particular problems for calculating depletion statistics, as there have been potentially large gains or proportionally smaller losses along this section of the Victorian coast, especially for Lake Wellington. The primary difficulty is with existing areas of coastal saltmarsh, some of which are natural occurrences, some of which seem to be expansions of saltmarsh since European colonization. Given this uncertainty, we calculated upper and lower bounds on the depletion estimates for the Gippsland Lakes sector, based on two extreme scenarios:

> Scenario 1: All the ambiguous saltmarsh areas are natural.
>
> Scenario 2: All the ambiguous saltmarsh areas are recent expansions, in which case they are counted as gains which offset other losses.

Our analysis indicates that, in the mid 19th century, Victoria supported approximately 346–421 km^2 of coastal marsh, of which on a State-wide basis approximately 80–95% remains (depending on which of the two scenarios for the Gippsland Lakes are employed). The overall value of 80–95% can be further dividied into values of 92% remaining for mangroves on a State-wide basis, and 75–95% for the other types of coastal wetland (Table 4).

Fig. 5. Housing immediately behind coastal saltmarsh at Hastings, Western Port.

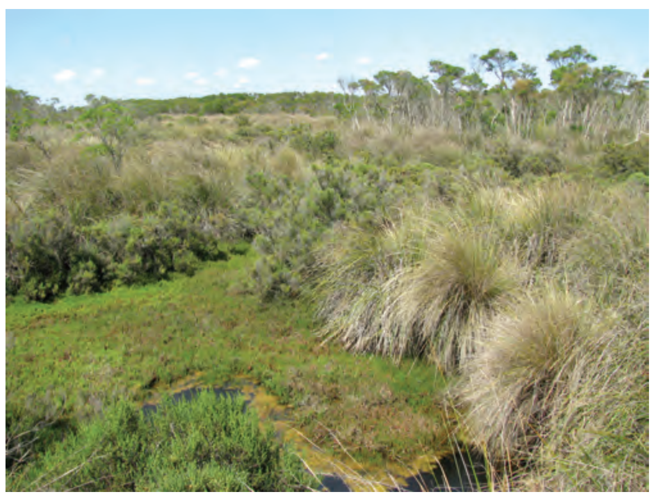

Fig. 6. Photograph showing the structural and floristic complexity of Victorian coastal saltmarsh.

Table 4 also demonstrates that historical changes to coastal wetlands have not been evenly spread along the coast: some sectors have experienced relatively little change since the mid 19th century, whereas others have been severely depleted. Proportionally large depletions have occurred, for example, in the Lonsdale Lakes area on the Bellarine Peninsula (approximately 60% depletion), the western shore of Port Phillip Bay (50% depletion), and the Powlett-Kilcunda and Anderson Inlet sectors of the South Gippsland coast (60–65% depletion). In some areas of the coast (e.g. Glenelg and parts of the Gippsland Lakes), there may have been an expansion of coastal marsh since European colonization. Figure 2 shows as examples pre-European and present-day marsh distributions for two areas of the Victorian coast: the Bellarine Peninsula and Anderson Inlet.

The following section details some of the site-specific matters that are relevant for each of the coastal sectors used in the analysis. Bioregions are shown in brackets and abbreviated as per Table 3. The discussion concerns primarily extent of marsh and does not address possible change in ecological condition; the latter could not be easily or consistently

Table 4: Estimated areas of Mangroves (M) and Other Coastal Marsh (OCM: mostly a combination of Coastal Saltmarsh and Estuarine Wetland) in various sectors of the Victorian coast before European colonization (pre-1750 area) and as at ~2008 (present-day area). All values for pre-European areas have been rounded to the nearest 10 ha and, for depletion figures, to the nearest 5%; present-day areas are known with better accuracy and are thus shown to the nearest ha. Two scenarios are given for the two coastal sectors associated with the Gippsland Lakes (Lake Wellington; and Lakes Victoria and King) as described in the text. Any recorded expansion in marsh area from pre-European times is shown simply as >100 rather than as a numerical value. ? = unknown. See text for discussion of limitations.

Sector	Pre-1750 Area (ha)			Present-day area (ha)			Retention (%)		
	M	OCM	Total	M	OCM	Total	M	OCM	Total
Glenelg		40	40		54	54		>100	>100
Fawthrop-Belfast		120	120		67	67		55	55
Western estuaries		590	590		606	606		100	100
Aire-Gellibrand		220	220		222	222		100	100
Surf Coast estuaries		30	30		31	31		100	100
Breamlea		410	410		363	363		90	90
Connewarre-Barwon	40	2230	2270	49	2023	2073	>100	90	90
Lonsdale Lakes		390	390		162	162		40	40
Salt Lagoon		40	40		36	36		90	90
Swan Bay		560	560		483	483		85	85
Mud Islands		40	40		36	36		90	90
Port Phillip	?	3710	3720	6	1767	1773	?	50	50
The Inlets	10	110	110	8	59	66	80	55	60
Western Port	1320	1460	2790	1230	1287	2516	95	90	90
French Island	480	1010	1500	475	1002	1476	100	100	100
Rhyll Inlet	90	130	230	93	119	212	100	90	95
Lang Lang coast		20	20	2	29	31	>100	>100	>100
Bass River	10	230	240	15	165	180	>100	70	75
Powlett-Kilcunda		200	200		75	75		35	35
Anderson Inlet	130	1120	1250	158	434	592	>100	40	45
Shallow Inlet	170	300	480	0	180	180	0	60	40
Wilsons Promontory	50	130	190	54	135	189	100	100	100
Corner Inlet	1060	1350	2410	846	513	1358	80	40	55
Nooramunga coast	1020	2820	3840	994	2263	3257	95	80	85
Nooramunga islands	1240	2100	3350	1247	2236	3483	100	>100	>100
Jack Smith Lake		1920	1920		1839	1839		95	95
Lake Reeve		3530	3530		3043	3043		85	85
Lake Wellington - Senario 1		5560	5560		3638	3638		65	65
Lake Wellington - Senario 2		480	480		3638	3638		>100	>100
Lakes Victoria and King - Senario 1		4940	4940		4019	4019		80	80
Lakes Victoria and King - Senario 2		2510	2510		4019	4019		>100	>100
East Gippsland inlets		1160	1160		995	995		85	85
Total - Senario 1	**5650**	**36480**	**42120**	**5175**	**27878**	**33053**	**92**	**75**	**80**
Total - Senario 2	**5650**	**28970**	**34620**	**5175**	**27878**	**33053**	**92**	**95**	**95**

inferred by the methods used in our study. Note also that the whole-of-State perspective inevitably leads to a glossing-over of some losses that were of comparatively minor extent; such a bias should not be seen to trivialise the smaller losses that have taken place since European colonization.

Glenelg (Brid)

This small, isolated sector has always contained a relatively small area of coastal marsh, and much of it remains intact. Field work indicated that areas of Estuarine Wetland and Estuarine Reedbed (EVC 10 and EVC 952, respectively), has apparently been converted to pasture, particularly between the Glenelg River and the South Australian border. It is possible that there has been a minor increase in the total area of coastal marsh in this sector (Table 4).

Fawthrop-Belfast (Fawthrop VVP; Belfast WaP & VVP)

Field work and several early plans indicate that significant change has occurred to the extent of intertidal marsh in this relatively small area (Anon c.1843, 1843, 1850, Barrow undated, Myers 1843). Fawthrop Lagoon near Portland has suffered very considerable hydrological change through channelling, changes to its catchment, and the conversion of the outlet to an artificial channel. The freshwater-saltwater boundary is now sharply defined by a causeway. Despite these changes, the basic shape of the lagoon probably remains the same in the saltmarsh zone (Stanley 1869*a*). There is no evidence for a substantial loss of coastal saltmarsh here, but it is likely that the brackish zone was once larger (indicating a likely loss of EVC 10 Estuarine Wetland). Since the mouth of the Moyne River has been permanently open at Port Fairy, Belfast Lough has been permanently exposed to the Southern Ocean. It now contains meadows of seagrass in the sub-tidal zone (*Zostera muelleri*, Ball & Blake 2009) and large expanses of saltmarsh. This wetland, however, was shown in 1843 as being 'fresh during the winter months' (Myers 1843). Although that evidence is cursory, it suggests that the wetland has become saltier, which probably allowed saltmarsh to increase at the expense of EVC 10 Estuarine Wetland (we have assumed half the area was once Estuarine Wetland for the purposes of area calculations.) As well, the wetland has been drained around its margins.

Western estuaries (WaP)

This sector includes the estuaries of the Surrey, Fitzroy, and Curdies Rivers, along with the intermittently open and closed coastal lagoon Lake Yambuk, in the west of the State. All are located in an agricultural landscape in which native vegetation has been almost entirely removed, including formerly vast areas of freshwater wetland. Extensive field work for this and a previous project (Sinclair & Sutter 2008) indicate that intertidal wetland vegetation was naturally restricted, and its post-European loss has been very small and proportionally relatively minor. The direct historic record, however, is sparse (Barrow 1853, Urquart undated, Anon 1854, Watson 1855) and field work suggests coastal marsh was probably restricted to small patches in Rutledge's Cutting and at the original mouth of the Merri River (near Thunder Point, Warrnambool), at the mouth of the Fitzroy River, and the lower portions of Lake Yambuk. In all cases, only *Sarcocornia quinqueflora*– and tussock-dominated (*Gahnia filum* or *Austrostipa stipoides*) saltmarsh is present, along with EVC 10 Estuarine Wetland. Most of these patches remain and have suffered only modest losses since European colonization. As shown in Table 4, we estimate the pre-European extent of non-mangrove coastal marsh as 590 ha and the current-day extent as 606 ha.

Fig. 7. Coastal saltmarsh at the mouth of the Powlett River in South Gippsland.

Fig. 8. Small-scale disturbance created in coastal saltmarsh by vehicular traffic. Note the new habitat created in the pools left by the vehicle tracks.

The loss of Estuarine Wetland is difficult to assess, particularly as sparse stands of *Juncus kraussii* may remain in grazed pasture after the removal of many other species that may be associated with a range of EVCs other than Estuarine Wetland (e.g. EVC 952 Estuarine Reedbed, EVC 953 Estuarine Scrub). Losses may have occurred in the hind-dune marshes on the Fitzroy River, and possibly also on the lower Merri River, although extensive drainage works between 1859 and 1870 and sand movement have changed the system radically (Anon 1854, Sinclair & Sutter 2008). All the losses in this sector of the coast are related to pasture creation, through drainage works and/or through continual grazing by stock.

Aire-Gellibrand (Gellibrand WaP; Aire OtP)

The Aire and Gellibrand River systems drain steep hills which experience some of the highest rainfall in Victoria (Table 3). The rivers discharge across large floodplains separated from the sea by natural barriers. Neither estuary currently supports mangrove vegetation, and there is no evidence that either did in pre-European times. Both river systems, however, support extensive stands of Estuarine Wetland. Field inspection and a recent mapping study of the entire Aire floodplain (Osler *et al*. 2010) confirm that extensive drainage works have radically altered its hydrological character, and led to extensive losses of native vegetation. Estuarine Wetland seems to have suffered only small declines, although it is difficult to reconstruct its exact pre-1750 distribution (Osler *et al*. 2010).

Surf-coast estuaries (OtP)

This sector of the coast supports only small patches of coastal marsh vegetation and has suffered some significant changes since European colonization, and there seems not to have been much loss of coastal marsh (Table 4). The Erskine River at Lorne retains much of its Estuarine Wetland. Painkalac Creek at Aireys Inlet also remains largely intact and supports mostly a *Sarcocornia quinqueflora*–dominated saltmarsh herbland and EVC 10 Estuarine Wetland. Changes have been greater on the Anglesea River. Here, a section of coastal marsh on the western side of the inlet was filled and converted to an urban park and roadway (Osler *et al*. 2010). Interestingly, the Anglesea River has recorded an increase in EVC 10 Estuarine Wetland, which has invaded areas of former Estuarine Scrub that were burnt and bulldozed in the 1983 fires (Osler *et al*. 2010). The tiny areas of saltmarsh and EVC 10 Estuarine Wetland on the Spring Creek at Torquay have been fragmented and reduced in area by incremental works on the shoreline, plantings and weed invasion. Overall, however, there has been little or no change in the area of coastal marsh in this sector since European colonization.

Breamlea (OtP & VVP)

Early plans (Smythe 1847, Daintree *et al*. 1863) show that the extent of coastal saltmarsh across most of this sector also has changed little since the early days of pastoral settlement, despite a history of varied and intensive land use. The eastern end of the marsh at Breamlea abuts a wastewater-treatment plant, which has destroyed a portion of the original wetland. The other substantial loss of coastal marsh occurred as a result of the landfill located at the south-western end of the sector, and a lagoon which was once located between Salt Swamp (Connewarre-Barwon sector) and Breamlea has been destroyed as well. Other incremental losses have occurred as a result of drainage for pasture, particularly in the north and centre of the sector. We estimate the total loss of coastal marsh to be of the order of 10% (Table 4).

Connewarre-Barwon (OtP & VVP although not mapped as such)

The lower Barwon River system remains a formidable and complex area of coastal marsh, despite its proximity to the large cities of Melbourne and Geelong and the long regional history of European land use. The historical record is detailed (Smythe 1847, Byerley 1855, Daintree & Ross 1862*a*) and shows that significant losses of marsh have occurred as a result of drainage for pasture in the south-western corner, at the southern boundary of Salt Swamp, along the course of the Barwon River (notably the southern side), and on the eastern side of Lake Connewarre. Comparatively minor losses have occurred elsewhere through dumping of material, development and weed invasion. Interestingly, it is possible that some small (<10 ha) gains in saltmarsh extent have also occurred since colonization, with areas on Paceys Island which were once wooded with EVC 953 Estuarine Scrub (probably *Melaleuca lanceolata*) having been converted to 'saltmarsh' through loss of their overstorey (Byerley 1855). The overall loss of non-mangrove marsh however, is likely to be small and, as with the previous sector, only of the order of 10%. The area of mangroves may have expanded by 20%, but as the original area was small (40 ha) this represents an increase of <10 ha (Table 4).

Lonsdale Lakes (OtP)

This section of the coast has suffered significant losses (approximately 60%) of a diverse range of saltmarsh types from the time historical data are available (Hoddle 1843, Byerley 1855, Daintree & Shepherd 1863*a*). The losses result from the accumulation of many local changes involving drainage, conversion to pasture, and the disruption of natural hydrological regimes through the construction of roadways. The Lonsdale Lakes were once more-or-less joined to Swan Bay by an expanse of marsh vegetation. Only a small section of this on the margin of Swan Bay is recorded as 'samphire' by Hoddle (1843) (i.e. succulent chenopods); the remainder was coastal marsh of unknown type. The loss of this area, apparently partly filled in to make way for suburban Point Lonsdale, is recorded in this sector, not Swan Bay.

Salt Lagoon (OtP)

Despite being surrounded by semi-urban development, agricultural land and roads, Salt Lagoon has largely retained its former shape and area (Daintree & Shepherd 1863*b*). All losses are of very minor extent.

Swan Bay (OtP)

Sand movement has altered the entrance to Swan Bay markedly since European colonization, partly as a result of natural processes, partly due to coastal engineering works. It is difficult to tell from the primary historical resource (Hoddle 1843, CHW Ross 1859, Cox & Stanley 1874, numerous maps of Port Phillip Bay) how much change in marsh extent these developments have caused. Although we assumed no change in extent at the entrance, saltmarsh has certainly been lost at the south-western end of Swan Bay because of the construction of roads and railways. Some small losses have occurred to the north and north-west as a result of drainage for pasture, but the saltmarsh was evidently always narrow in this region, as the hinterland rises quickly. The Edwards Point area retains essentially all its pre-European area of marsh. We estimate the overall loss in this sector to be about 15% across all marsh times.

Mud Islands (No bioregion assigned)

Due to their isolation within Port Phillip Bay, Mud Islands have been largely free from the development pressures that have led to the destruction of so many other coastal marshes in Victoria. But this is not to say this area has been static: historical records collated by Yugovic (1998) demonstrate that natural geomorphic processes have changed the shape of the islands and the marsh greatly since the early 19th century. Even so, we have assumed that there has been no net loss of saltmarsh vegetation since European colonization.

Port Phillip (VVP & OtP)

This sector has suffered massive losses of coastal marsh, brought about by intensive land-use, particularly ponds for sewage water treatment and salt production along the western shore. Fortunately the historic record is extensive and detailed (Russell 1837, Anon 1841, Garrard & Shaw 1850, Christie 1853, Ross 1859, Daintree & Ross 1862*b*, Cox 1864, Noone 1880*a*, 1880*b*, Goldsmith & McGauran 1896, Proeschel undated). The marshes which originally occurred in inner Melbourne and the port area have been destroyed by the growing city. The marshes of Altona retain much of their area, but have been corralled within a largely suburban landscape. The Cheetham wetland at the mouth of Skeleton Creek has been almost entirely converted to evaporation ponds, and the upper marsh has been replaced by the Sanctuary Lakes housing development. The once extensive string of marshes that stretched between the Werribee River and Point Wilson has been obliterated by the Western Treatment Plant. Similarly, the large marshes between Point Wilson and Limeburners Bay, along with the marshes of Point Henry, have been almost fully converted to salt ponds. Only the RAAF Lake and The Spit (Point Wilson) remain as large, relatively intact marshes in this part of the Victorian coast. Overall, we estimate the loss of coastal marsh (mainly saltmarsh rather than mangroves) at approximately 50%.

The Inlets (GipP)

The Inlets have lost up to 40% of their original coastal marsh, mainly as a result of the loss of saltmarsh and estuarine wetlands rather than of mangrove (Table 4).

Fig. 9. Flowering Rounded Noonflower, *Disphyma clavellatum*.

Fig. 10. Extensive bed of Swampweed, *Selliera radicans.*

Today they present an unusual superimposition of the past and present. The once vast Koo Wee Rup swamp now discharges via large drains into Western Port. However, between the Inlets the imprint of the original tidal channels and portions of coastal marsh and other vegetation remains intact. The marsh is diverse, containing EVC 10 Estuarine Wetland, EVC 140 Mangrove Shrubland and EVC 9 Coastal Saltmarsh Aggregate of many kinds, including *Sarcocornia quinqueflora* herbland, *Tecticornia arbuscula* shrubland, and tussock-dominated saltmarsh of *Gahnia filum* or *Austrostipa stipoides*. The largest losses have been west of Lyall Inlet, whereas most of the marsh east of Lyall inlet apparently remains intact (Smythe 1842*a*, Yugovic & Mitchell 2006). This is not to say, however, that vast areas of other types of wetland (e.g. EVC 53 Swamp Scrub) have not been lost following the drainage of Koo Wee Rup Swamp (see Introduction).

Western Port coast (GipP)

The Western Port coast retains a massive area of intact coastal marsh, including EVC 140 Mangrove Shrubland, EVC 10 Estuarine Wetland and EVC 9 Coastal Saltmarsh Aggregate dominated either by *Sarcocornia quinqueflora* or *Tecticornia arbuscula*. It has also suffered local historical losses as a result of infilling and drainage, and agricultural, urban and industrial development. The primary historic resource is good for Western Port, and consists of several early survey plans and aerial photography taken prior to extensive land-building (Smythe 1842*a*, 1842*b*, 1842*c*, 1842*d*; Bailliere 1866, Air Photo Westernport (868) A2 Central Plans Office neg. No. 20898 (1958)). The construction of the Hastings foreshore and marina resulted in the destruction of approximately 33 ha of saltmarsh, and the industrial developments at nearby Long Point resulted in the destruction of a further 23 ha. HMAS Cerberus near Sandy Point also required minor land-claims into former saltmarsh. Apart from these major developments, infilling and drainage for pasture have also destroyed large expanses of marsh, particularly from Watson's Inlet around to Yallock Creek; and near Stockyard Point. In contrast, the marshes on Phillip Island and the Gurdies–Grantville coast remain largely intact despite being bordered by private land, and have suffered only slight losses through drainage and grazing. This retention of coastal wetland in the bioregion is presumably a function of the slightly steeper terrain at the inland border of the marshes. We estimate that overall losses have been proportionally small, probably <10%. Even so, because of the large original area of coastal marsh the total area thought to have been lost is substantial, at over 250 ha (Table 4).

French Island (GipP)

The vast stands of pre-European coastal marsh and mangroves on French Island remain almost entirely intact (Smythe 1842*b*; Bailliere 1866). Some losses have occurred as a result of clearing of Mangrove Shrubland (e.g. see Lacey 2008), and some estuarine wetland has been converted to pasture in the upper Redbill Creek; extensive artificial ponds have modified but not removed much of the saltmarsh on the north-eastern coast.

Rhyll Inlet (GipP)

Although it retains substantial areas of coastal marsh (mostly Mangrove Shrubland and *Tecticornia arbuscula* Coastal Saltmarsh), Rhyll Inlet has suffered losses since European colonization. The rubbish tip on Cowes-Rhyll Road has obliterated 5 ha of coastal marsh, and extensive drainage works on the eastern end near Cowes have destroyed more. A detailed early map (Smythe 1842*b*) suggests that the spit sheltering Rhyll Inlet has lengthened since colonization, and there may have been some modest expansion of coastal marsh at the eastern end of the inlet. Overall, losses have probably been <10% of the pre-European area (Table 4).

Lang Lang Coast (GipP)

The Lang Lang coast is unusual in that it shows a likely increase in the extent of coastal marsh since European colonization (see also Lake Wellington and Lakes Victoria and King). At settlement, this section of the Victorian coast contained virtually no saltmarsh or mangroves, and was fringed instead with a dense stand of Swamp Paperbark *Melaleuca ericifolia* where the Tobin Yallock Swamp directly met the sea (Smythe 1842*c*; Yugovic & Mitchell 2006). Fresh water spilled from this swamp, an event described by Smythe (1842*c*) as 'numerous rills of freshwater continually running'. The coast at this time was probably cliffed and eroding (Yugovic & Mitchell 2006). Drainage, however, has left the former landscape unrecognisable. A series of bund walls now line the coast, and fresh water is channelled to the sea. A band of saltmarsh has formed on and in front of the bund walls, above the intertidal zone, and presumably receives salty water from ocean spray. This marsh is mostly species-poor *Sarcocornia quinqueflora* herbland. Small areas of remnant marsh occur only at the abandoned mouth of the old Yallock Creek.

Bass River (GipP)

Pasture-creation has destroyed a large proportion of the marsh on the Bass River estuary, with almost the entire margin being bounded by walls, drains or fill. The invasive Cord-grass (*Spartina* spp.) grows in extensive mats in channels and on mudflats throughout the marsh, and has resulted in the exclusion of native-dominated marsh in places. Interestingly, an early plan of Western Port (Smythe 1842*c*) does not show any mangroves at the mouth of the Bass River, despite showing them elsewhere, including nearby at Settlement Point. Whether the extensive stands which now exist are a recent invasion is doubtful, and it is conceivable that the survey plan was incomplete. Overall, losses of coastal marsh may have been of the order of 25% (Table 4).

Powlett-Kilcunda (GipP)

The small portion of marsh at Kilcunda, supporting a range of saltmarsh types and EVC 10 Estuarine Wetland, retains most of its former extent. The Powlett River also retains most of its original saltmarsh, but large areas of Estuarine Wetland have probably been lost to pasture on the large plain to the north east of the river mouth. Proportionally, this sector of the coast has suffered among the greatest losses of coastal wetland; we estimate the loss to be about 65%, or about 125 ha (Table 4).

Anderson Inlet (GipP)

Anderson Inlet has experienced some of the largest absolute and proportional losses of coastal marsh anywhere in Victoria since surveys were first undertaken in the 19th century (Smythe c.1847; Stanley 1869*a*, 1869*b*, Anon undated *a*). Much of the saltmarsh and mangrove areas have been destroyed following extensive drainage works for conversion to pasture, and we estimate that only 40% of the original non-mangrove marsh remains (Table 4). Losses have been very substantial at the eastern end of the Inlet, and around the mouth of the Tarwin River. Moving sands also have had a minor impact on saltmarsh extent near Point Smythe. The spread of *Spartina* in the Inlet ensures that changes continue (Blood 1996).

Shallow Inlet (GipP)

This section of the coast has also undergone substantive changes since European colonization, representing some of the largest losses of coastal marsh in Victoria. Land-building works have destroyed vast areas of marsh, particularly on the southern side of the inlet. Bird (1993, Figure 167) shows the loss of wetland that has occurred since European colonization. Interestingly, both the early plans consulted for this part of the coast show extensive areas of both 'mangroves' and 'samphire' (i.e. saltmarsh) (Smythe 1848, Anon undated *a*). There are currently no mangroves in Shallow Inlet, and unless we assume both early plans were in error, it would seem that the prior stands (perhaps ~170 ha in total) have been entirely lost.

Wilsons Promontory coast (WPro)

This small sector is entirely within a National Park and is bordered by intact native vegetation. The Park was reserved in 1898, gazetted in 1905, and progressively added to in 1908, 1928, 1947 and 1969. Although there has been sporadic use of the Park's terrestrial and coastal resources (Parks Victoria 2011), it seems to be the case that coastal saltmarsh or mangroves have suffered no measurable decline in extent.

Corner Inlet coast (GipP)

Some of Victoria's largest losses of saltmarsh have occurred in this sector, and we estimate that only about 45% of the pre-European area of coastal marsh remains (Table 4). Losses have been mainly of saltmarsh rather than of mangrove, and about 80% of the pre-European area of the latter remain today. Most of the existing saltmarsh is bordered by channels and walls/levees, and the upper marsh has been drained and converted to pasture. Unfortunately the historic record seems to lack detail at a fine scale (Smythe 1848, undated *a*, Wright 1849, Anon undated *b*), however field observations, aerial photographs and elevation data come together to provide strong and consistent evidence of former marsh extent. For the purpose of area calculation, we delineated a putative pre-

Fig. 11. *Juncus acutus*, an exotic weed now found in many coastal or salinized wetlands in Victoria. This photograph is of wetlands in the Seaford-Frankston Swamp area to the south of Melbourne.

Fig. 12. Roots and pneumatophore of the mangrove *Avicennia marina* exposed by coastal erosion in the Grantville area of Western Port.

1750 boundary between mangroves and saltmarsh, using intact areas to guide us in the relative widths of these bands.

Nooramunga coast (GipP)

Although the historic record is detailed around Port Albert (Anon 1842, Smythe 1843, Anon undated *c*), it is poorly resolved elsewhere in the sector. Like Corner Inlet, however, much of the marsh is now bounded inland by sea walls and channels, which provide direct evidence of the extent to which the landscape has changed. Losses of mangroves have probably been of the order of 5% and of other coastal marsh types of up to 20% (Table 4).

Nooramunga islands (GipP)

The Nooramunga islands remain almost entirely uncleared and undeveloped and, as such, probably represent the least disturbed large sector of coastal marsh on the Victorian coast. The marshes include extensive stands of EVC 140 Mangrove Shrubland, and EVC 9 Coastal Saltmarsh Aggregate mostly dominated by *Tecticornia arbuscula*, *Sarcocornia quinqueflora Gahnia filum* or *Austrostipa stipoides*. Although we are aware that geomorphic changes have taken place in the area since settlement, the historic record does not allow an accurate reconstruction to be made of past patterns (Smythe 1848, Wright 1849, Smythe undated *b*, Anon undated *b*); thus we have assumed that the extent of marshes in this area has remain unchanged since European colonization.

Jack Smith Lake (GipP)

The historic record for Jack Smith Lake is poor (Smythe undated *d*), and field inspection and aerial photograph interpretation suggest that much (95%) of the marsh area remains, but with small areas lost to infilling, drainage and grazing.

Lake Reeve (GipP)

Lake Reeve itself retains most (~85%: Table 4) of its former area of marsh, with the exception of one large area claimed for pasture at the western end. The historic record is detailed and shows the vegetation has otherwise changed very little in its extent since the early 19th century (Smythe undated *c*, undated *d*, undated *e*, Anon undated *d*). Perhaps the biggest losses have been outside Lake Reeve itself, but included in this sector: Smythe (undated *c*) shows extensive patches of 'saltmarsh' between Lake Reeve and Lake Wellington (>750 ha in total; distinguishable from areas labelled 'swamp' and 'tea-tree'). Such areas were clearly not intertidal, but presumably interacted with saline groundwater. Similar patches of 'coastal' marsh lacking tidal connection exist elsewhere (e.g. Lonsdale Lakes). The examples near Lake Reeve have largely been converted to pasture and, in one case, a farm dam.

Lakes Victoria and King (GipP)

The ever-shifting natural entrance to the Gippsland Lakes from Bass Strait was replaced by a permanent opening as a result of engineering works between 1870 and 1889 (Bird 1965, Bird & Lennon 1989). Bird (1966) marshalled evidence to indicate that the creation of the permanent opening to the Southern Ocean had caused an increase in salinity in the Gippsland Lakes system, leading to an increase in saltmarsh at the expense of freshwater wetlands. His conclusions are broadly supported by our fieldwork, which showed strong evidence of dieback of the fringing freshwater and brackish-water wetland systems. Nonetheless, the historic record shows clearly that saltmarsh was present and extensive around Lakes Victoria and King in the early 19th century. Saltmarsh or salt lakes apparently occurred naturally right around the lakes: maps show them in Victoria Lagoon and the surrounding depressions, in Jones Bay (Wilkinson 1849), around Loch Sport, Beacon Swamp, Blond Bay, Point Wilson, near Paynesville, on the Mitchell Silt Jetties (Smythe undated c, undated d; Wilkinson 1849), on Raymond Island (Anon undated *e*) and on the Boole Poole Peninsula.

As noted in the Methods, two scenarios are shown for the change in coastal marsh area in Lakes Victoria and King. Under Scenario 1, we estimate that there were 4,940 ha of non-mangrove marsh prior to European colonization. About 80% remains today (Table 4). Under Scenario 2, however, the pre-European estimate falls to 2,510 ha and thus there appears to have been a very substantial increase in the area of saltmarsh (of the order of 1,500 ha) in this part of the Gippsland Lakes. It would thus appear that saltmarsh has expanded in some places around the Gippsland Lakes, remained static in others, and decreased in others. Direct losses of coastal saltmarsh, caused by local land-claims, have in comparison been minor. Given the uncertainty as to whether some large expanses of marsh are remnant or adventive, we have presented two extreme scenarios for this sector (as described above).

Lake Wellington (GipP)

Like Lakes Victoria and King, Lake Wellington and its fringing wetlands have been strongly influenced by the opening of the artificial entrance to the ocean at Lakes Entrance (Boon *et al*. 2008, Raulings *et al*. 2010). Bird (1965, 1966) suggested that Lake Wellington was once essentially a freshwater lake, and that the saltmarsh on its margins has invaded recently, replacing prior freshwater systems. The historical record partially supports this view. Myers (c.1840) shows Lake Wellington as 'fresh' (Lake Reeve is shown 'Salt'; Lakes Victoria and King are unannotated). In contrast, other early sources (Smythe undated c; Anon undated e) show very extensive areas of saltmarsh interlaced with 'tea tree' and 'swamp' on the southern margins of Lake Wellington (and Lake Coleman), and in many depressions inland between Lake Wellington and Lake Reeve (see Lake

Reeve sector, above). In his more-detailed 1965 study used as a basis for the 1966 synthesis, Bird acknowledged the natural (more inland) occurrence of these saltmarsh areas. There is, however, no evidence for an extensive pre-European occurrence of saltmarsh on the western and northern shores of Lake Wellington, which suggests that it has expanded its overall area on this part of the coast.

As for Lakes Victoria and King, we provide two scenarios for Lake Wellington in order to account for several large periods of uncertain history. There is a substantial difference in the areas of pre-European coastal marsh yielded by the two approaches: Scenario 1 gives an estimate of 5,560 ha, whereas Scenario 2 gives a much lower value of 480 ha. Which of the two scenarios is employed has a major impact on the amount of coastal marsh estimated to be lost (or gained) since the middle of the 19th century (see Table 4).

East Gippsland inlets (EGL)

Although little direct evidence of saltmarsh loss could be found for this sector of the coast in the historical record, an inspection of aerial photographs reveals land-claims on the lower Snowy River, which have apparently lead to large, local losses of coastal marsh (probably dominated by *Sarcocornia quinqueflora*) and Estuarine Wetland (Lees 1855, Anon undated *d*, undated *f*). We estimate the loss in this sector to be about 15%.

Discussion

What Australian landscapes looked like, what vegetation was present, and how it was patterned before European colonization are topics that have become of increasing interest to many researchers and natural-resource managers over recent decades (e.g. see Benson & Redpath 1997, Lunt 1997, 1998, 2002, Griffiths 2002, Hateley 2010). Concurrent with this widespread interest, maps that accurately represent vegetation patterns before European colonization also have become increasingly important to researchers and managers, and are commonly called 'pre-1750 vegetation' maps or similar. As well as being historically interesting in their own right, such maps provide a reference point to calculate relative degrees of change and depletion and are sometimes used as aspirational targets for restoration of degraded environments (Oliver *et al*. 2002). In Victoria the degree of depletion is also essential information for determining the conservation status of vegetation (the BCS, or 'Bioregional Conservation Significance') and in designing a reserve system that is 'comprehensive, adequate and representative' (Commonwealth of Australia 1997).

A tremendous conceptual difficulty with historical reconstructions of the pre-European Australian landscape is that there are 'radically different readings of the same landscape' (Horton 2000, page 72). As examples, controversy rages as to the nature of Aboriginal fires regimes and their ecological impacts (e.g. see Benson & Redpath 1997,McLoughlin 2004), the density of trees in terrestrial woodlands (Benson & Redpath 1997, Lunt 1997, 1998, Horton 2000, Griffiths 2002) and the intensity of the regrowth of so-called woody weeds (Benson & Redpath 1997). Against this background of the suite of methods available for analysis – all with limitations – is the possibility of a strongly political or ideological element to many of the interpretations that are made (e.g. see Horton 2000).

Loss of coastal marshes in Victoria

Difficulties in interpretation and their solution. In the case of coastal marshes, difficulties in interpretation are

Fig. 13. Dense stands of the mangrove *Avicennia marina* along the northern shore of Western Port, near the township of Tooradin.

Fig. 14. Housing immediately behind coastal saltmarsh and ephemeral saline pools at Hastings, Western Port. Compare with Figure 5.

compounded by the temporal dynamism of the vegetation and its structural simplicity. In some cases vegetation change is a simple case of subtraction: vegetation has been removed *in toto* from the landscape, so that current vegetation maps are simply 'cut outs' from the pre-1750 maps. Coastal marshes probably differ significantly from that simple scenario in that they may have expanded or contracted in different parts of Victoria since colonization; in some places saltmarsh now occurs in places where it did not before colonization. Many patches of coastal marsh are also small and intricately shaped, meaning they are not easily mapped when they have been destroyed and their size can be difficult to estimate without substantial error. Furthermore, saltmarshes do not leave behind easy clues for historical ecologists to unravel. When they have been 'reclaimed', the loss means that they have often been utterly destroyed through changes to the whole landscape, such as from land-claims using earthworks, extensive landscaping for saltworks or water treatment, or the removal of whole areas of marsh for marinas, ports, oil refineries and other types of coastal development. In contrast, many other vegetation types are removed without such wholesale alteration of the landscape and small pockets or remnant often remain as a clue to the original vegetation. When forests or woodlands have been removed, for example, the soil usually remains accessible for interpretation, as do a few relict trees. In contrast, coastal saltmarsh can disappear without a trace.

Calculating the area of coastal marshland that existed before European colonization and thus the degree of retention (and depletion) is further complicated by our need to deal with an always imperfect knowledge of the past and, especially, a limited or ambiguous understanding of the vegetation patterning that is reported in the historical sources. We are particularly uncertain as to whether some areas of coastal marsh in the Gippsland Lakes region are recent incursions of coastal marsh or remnants of pre-colonial wetlands. To address this uncertainty we offer two scenarios: Scenario 1, where all the ambiguous marsh is considered to be adventive (which offsets much of the other losses across the State); and Scenario 2, where it is all considered relict. These two scenarios differ greatly and the area of uncertain origin is very large, as shown in Table 4 and discussed earlier.

Similarly, it is also not clear how best to treat small areas of land or water that occur within the current area of coastal marsh, but which are not marsh vegetation – areas such as brine pools (including EVC 842 Saline Aquatic Meadow), bare mud, small 'islands' of sand or of higher land, and man-made structures such as in-fill and levees. As these areas are clearly not to be included as 'marsh' when compiling the figures showing current costal marsh extent, they were excluded in the Victorian Saltmarsh Study (2011). Despite this, the resolution of the historic maps and plans means that such areas are mostly included within areas shown as 'marsh' on the old maps. If the current and historic figures were taken at face value, many areas of non-marsh would be excluded from the current figures but included in the historic data, which makes for an unbalanced comparison. Unfortunately, we cannot know where the areas of brine pools, sand deposits and bare mud were in the past, since these areas change over decadal time-spans. Therefore we included all areas of non-marsh in the current total for Other Coastal Marsh. This makes the figures higher than those presented originally in the Victorian Saltmarsh Study (2011), as discussed next.

Magnitude of historic losses. Notwithstanding the difficulties of interpretation, our analysis shows that prior to European colonization Victoria supported approximately 56.5 km^2 of mangrove swamps and 290–364 km^2 of Other Coastal Marsh. These values sum to a total area of 346–421 km^2 for mangrove and non-mangrove coastal marsh combined. Present-day areas for mangroves were estimated at 51.75 km^2 and for other types of coastal marsh at 278.78 km^2 (Table 4). Thus, approximately 92% of mangroves and 75–95% of Other Coastal Marsh remains today on a whole-of-State basis. When these values are conflated, we estimate that overall, 80–95% of pre-European coastal marsh remains in Victoria as of c. 2008.

The detailed mapping undertaken earlier by the Victorian Saltmarsh Study (2011) reported that there were 51.8 km^2 of EVC 140 Mangrove Shrubland in Victoria, as well as 192.1 km^2 of EVC 9 Coastal Saltmarsh Aggregate, 32.3 km^2 of EVC 10 Estuarine Wetland, and 6.5 km^2 of EVC 196 Seasonally Inundated Sub-saline Herbland. Together, the area of these non-mangrove coastal marshes sums to ~231 km^2. Not unexpectedly, there is agreement between our and the previous (Victorian Saltmarsh Study 2011) estimates of the current-day area of mangroves. The apparent discrepancy for non-mangrove coastal marshes arises because in order to allow a valid comparison to be made of current-day and pre-European data sources we had to include all areas of non-marsh in the total for Other Coastal Marsh, as described above. (The total area is calculated at 278.78 km^2 in Table 4 and is thus about 20% higher than in the earlier State-wide estimate.)

Geographic and floristic variations. Although the State-wide loss of coastal marsh has been of the order of only 5–20%, some parts of the coast have experienced relatively little change since the mid 19th century, whereas others have been severely depleted and in a few areas there has been an expansion of coastal marsh, both of mangroves and of coastal saltmarsh/estuarine wetland. As noted earlier, the situation with the Gippsland Lakes is complex and problematic, and according to the method used to interpret the original data sources, there has either been a substantial increase or a slight loss (~10–20%) in the area of coastal wetlands in this part of Victoria. In many of the coastal sectors, however, losses have been minor (<10%) and in many cases there is almost the same area of coastal marsh now as in pre-European times.

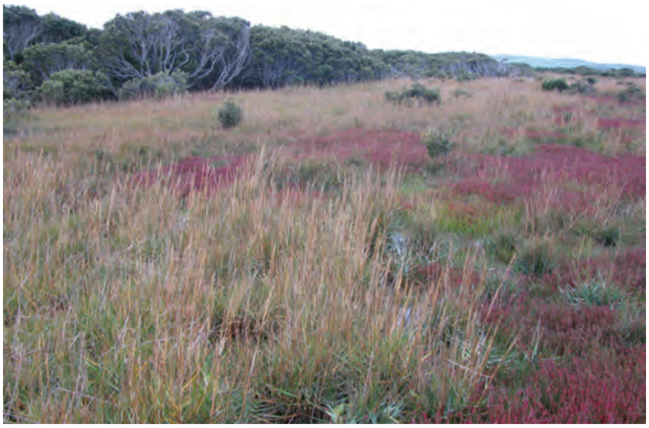

Fig. 15. The exotic Cord-grass *Spartina* growing at Anderson Inlet.

Fig. 16. Loss of coastal saltmarsh from the Hastings area of Western Port as a result of urban housing and the creation of sports fields.

A distinction has often been drawn between two general forms of saltmarsh on the Victorian coast (Barson & Calder 1981). The first, a 'dry' type, is present mostly in the central-western parts of the State, where low summer rainfall and high temperatures lead to intensely hypersaline conditions in the more elevated sites. Here the vegetation is dominated by *Tecticornia pergranulata* and *Tecticornia halocnemoides*. The second, 'wet' type, is found where rainfall is higher, mostly in the eastern part of the State, including Western Port; the vegetation in this saltmarsh type is dominated by samphires such as *Sarcocornia* spp. and *Tecticornia arbuscula*. Given the composition and ecology of coastal saltmarsh differs greatly between different sectors, our figures could mask potentially large changes for some species or saltmarsh types. Although the historic data are not sufficiently detailed to permit a quantitative state-wide analysis at the level of species or saltmarsh types, a qualitative consideration of likely losses in each sector may reveal some of this pattern.

Across the State, the largest absolute losses have probably been of EVC 140 Mangrove Shrubland, and coastal saltmarsh dominated by *Tecticornia arbuscula*, and the main losses have occurred in Lonsdale Lakes, western shore of Port Phillip Bay, Anderson Inlet, Shallow Inlet, Powlett-Kilcunda, Corner Inlet and Nooramunga. All these regions except the first two are located along the coast of Gippsland, an area of Victoria that experienced very considerable development for agriculture, mining and industry (Wells 1986, Watson 1997). The large proportional losses in western Port Phillip Bay have occurred with marshes that occur along lower-rainfall coast; here the dominant taxa are *Tecticornia pergranulata*, *Tecticornia halocnemoides* and *Disphyma crassifolium*.

Fig. 17. One of the more pristine coastal marshlands in Victoria: the mouth of the Thurra River in East Gippsland.

Fig. 18. *Tecticornia arbuscula* growing in a saltmarsh along the eastern shore of Port Phillip Bay.

Comparison with losses of coastal marshes elsewhere

The proportion of overall wetland loss for Victoria seem not to be as severe as have been reported for New South Wales and Queensland, where losses of 30–70% since the 1940s–1950s are not uncommon (Saintilan & Williams 2000, Harty & Cheng 2003). The comparison is, however, made difficult by the different time frames of the various investigations; our study quantified losses since the middle of the 19th century, whereas Saintilan & Williams (2000) and Harty & Cheng (2003) studied losses only since approximately World War 2, when aerial photography became widely used for landscape analysis and mapping (Fensham & Fairfax 2002).

The losses also appear to be relatively small in comparison with many Northern Hemisphere coastal systems, where losses of 20–60+% are not uncommon (Doody 2008; Gedan & Silliman 2009). In addition to the statistics cited in the Introduction, it may be noted that, in the USA, ~50% of the original saltmarsh of Narragansett Bay has been filled in, 73% of the original saltmarsh lost from Puget Sound, and 95% from San Francisco Bay (Doody 2008). Using historical maps, Bromberg & Bertness (2005) concluded that the average loss of New England (USA) marshes since the early 1800s was 37%; Rhode Island had lost 53% of its coastal saltmarshes since 1832, and the Boston area had lost 81% since the late 1700s.

The apparently small overall proportional loss in Victoria compared with other coastal areas is attributable to a number of factors. The first is that a great deal of coastal marsh occurs on relatively inaccessible islands, notably in the Corner Inlet–Nooramunga area. The second is that Victoria has had a history of agricultural development and population growth that is much shorter than those of coastal areas in the Northern Hemisphere. Furthermore, Victoria's agricultural sector has never suffered from an acute lack of space and dense settlement comparable with that in many other places (e.g. the Netherlands). All such comparisons are influenced also by historical and statistical accident: it is probably possible to delineate areas in North America or the Baltic of comparable size to Victoria that retain a great deal of coastal marsh, just as it is possible to select large areas in Victoria that show heavy losses. Added to this is the likelihood that studies reporting depletion tend to focus on areas under threat, rather than broader administrative units such as individual States or Territories. It is also important to note that the coastal marshes surveyed in this study do not tell the whole story about the loss of wetland ecosystems across the State. For example, near-coastal freshwater wetlands (often dominated by Swamp Paperbark *Melaleuca ericifolia*) have suffered enormous losses to agriculture, and they are not reflected in our analysis (East 1935, Callaghan 1948, Roberts 1985, Yugovic & Mitchell 2006).

In those places where losses have been significant, a large number of reasons can be outlined as being responsible (e.g. see reviews by Laegdsgaard 2006; Laegdsgaard *et al*. 2009; Thomsen *et al.* 2009). In some areas of Victoria (e.g. northern and eastern Port Phillip, and the western shore of Western Port), the creation of a large metropolis with associated port, industrial and residential zones is undoubtedly responsible. In many others, however, substantial losses have occurred in areas that have experienced little direct population pressure (e.g. Anderson Inlet, Shallow Inlet, and Corner Inlet). In these areas, drainage and infilling for agriculture have probably been responsible. In other cases, extraction of shell-grit, conversion into salt-making ponds, and burning for barilla production has been responsible for the loss of large areas of coastal wetland, as noted in the Introduction.

Ecological implications of the loss of coastal marshes

There is increasing concern across the world about the loss of coastal wetlands and, in temperate areas, of saltmarshes in particular (e.g. see reviews by Teal & Howes 2000, Kennish 2001, Adam 2002, Cattrijsse & Hampel 2006, Doody 2008, Callaway & Zedler 2009, Turner 2009). Silliman *et al*. (2009, page 391) went as far as to say 'salt marshes are under siege from human disturbance on a global scale. Salt marsh coverage as well as the structure of these ecosystems continues to deteriorate drastically due to human-induced changes. The critical ecosystem services these systems support are likewise endangered'.

Much of the concern arises because coastal wetlands are critical habitats for a wide range and large number of birds (Stevens *et al.* 2006, Faunch & Serafy 2006, Wilson *et al.* 2007, Spencer *et al*. 2009, Visser & Baltz 2009). In Victoria, coastal saltmarsh provides the overwintering foraging sites for the critically endangered Orange-bellied Parrot *Neophema chrysogaster* (Loyn *et al.* 1986). There is now growing evidence that the loss of coastal saltmarsh can be tied directly to population declines in some bird species (e.g. see Ganter *et al*. 1997, Wilson *et al*. 2007, Robledano *et al*. 2010, Jenner *et al*. 2011). Coastal wetlands have also long been known as critical sources of organic matter for adjacent estuarine waterbodies, although the mechanism by which the two interact is unclear (Teal & Howes 2000, Zimmerman *et al*. 2000, Kreeger & Newell 2000). Recent research, however, lends support to the notion that coastal saltmarsh is particularly important in terms of providing habitat for small invertebrates and fish, which then move into the estuary on out-going tides or when they are mature (e.g. see Stevens *et al*. 2006 for fish; Mazumder *et al*. 2006 for crabs), rather than supporting off-shore food webs by exporting vascular plant detritus. Thus it can be expected that the loss of coastal wetlands would have serious implications for estuarine food webs (e.g. see Svensson *et al*. 2007).

Conclusions

Our study documents the loss of coastal marsh across the State of Victoria from ~1835 to 2008. We believe it to be the first such study of this scale in Australia. Its scope reveals large regional differences between sectors of Victoria's coast, but this scale undoubtedly also glosses over many small changes, each with important impacts and interesting stories. It is hoped that the study encourages local studies in areas of particular interest or concern, and in this the recently available LiDAR data for the entire State will undoubtedly prove very useful.

Changes to coastal marshes have not stopped and are unlikely to cease in the near future. The destruction of coastal wetlands for industrial and port development remains an ongoing threat in many parts of Victoria (e.g. Western Port). A more widespread threat, of course, is that posed by climate change. In the absence of sufficiently rapid increases in sediment elevation (Morris *et al*. 2002, Rogers *et al*. 2006), rising sea levels will force coastal marshes to retreat upslope, a response which is impossible in many cases due to topography or human infrastructure (Gilman *et al*. 2008, Boon *et al*. 2010). Clearly, this is not the end of the story for the depletion of coastal marshes in south-eastern Australia.

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"Since the acceptance of this manuscript, several additional Parish Plans relating to the Gippsland coast have been brought to our attention. The plans have recently become available digitally via the National Library of Australia and/or the State Library of Victoria, and were not retrieved in our initial search. These plans are resolved at a fine scale, and provide interesting local detail and clarification, but do not alter the findings presented here. For the sake of future researchers who may wish to gain a more complete picture of the historical resource, the relevant Parishes are Alberton West, Balloong, Bengworden South, Nuntin, Sale, Tarra Tarra, Toora, Welshpool, Wonga Wonga South and Yanakie."

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