



Estuarine
Wetlands: Ecology,
Rehabilitation and
Management

3.1

Estuarine shorelines of southeastern Australia

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Abstract

The southeastern coast of Australia is the most densely populated portion of the country, and its estuarine wetlands are subject to pressures from agriculture, industry, and urban settlement. The geological architecture on which these wetlands stand has a long, complex and fascinating history, starting from the time when the eastern portion of Australia emerged to join the rest of the continent hundreds of millions of years ago. The subsequent creation of fold belts and sedimentary basins, uplifting and rifting, and rise and fall of sea level, have played a part in producing the coast with which we are familiar today. The key purpose of this chapter is for the readers to consider geomorphic background before undertaking management decisions, small or large, for the benefit of sustainable management of urban wetlands, especially estuarine wetlands, in Australia.

Introduction

The birth of the Australian continent began about 4.6 billion years ago with the consolidation of large rock masses in Western Australia, but it was not until much later that there was any land mass that could be considered the forerunner of the east coast. Beginning about 500 million years ago and continuing for many million years, separate geological events combined to produce the framework for the eastern shoreline. Over the past 60 million years, unlike the other continents, Australia has been geologically stable with little mountain building or extensive volcanic activity. The old geology, the one that created the architecture on which the current wetlands of eastern Australia stand, also supports the most densely populated sector of the country, with the wetlands subject to pressures from agriculture, industry, and urban expansion.

For many people, the only geological events along the southeast coast that are of interest are eroding beach or river foreshores, or sediment loads dropped after floods. It is the objective of this chapter to introduce some of the geological and geomorphological features that have influenced the position and shape of the estuarine wetlands of the southeastern coast of Australia, a sector defined as beginning at the Noosa River (sub-tropical Queensland) and continuing to Cape Howe (temperate New South Wales).

The history set out below has two nested timelines, the first being of the whole of the continent as it grew and shrunk, lifted and sank, flooded and drained, and changed its location mostly within the southern hemisphere. A second time line concerns the eastern side of the continent, a relatively recent addition to the continental land mass. It too has seen numerous changes that have brought the creation and erosion of large mountains, and changes to the geography of the foreshore, that bring us to the coast we know today.

Geological Framework

The geologic record is more detailed in the recent past than for the distant past due to some of the major geologic events that have overcome and swept away earlier features. The creation and breakup of the crustal plates through tectonic motion is but one example of how the surface of Earth has changed, meaning that in some cases there is little record of previous landforms. Where details are available, geologists have been able to break Earth's evolution into distinct time slices. An

overview of these time frames (Table 3.1.1) assists in defining the terms “eon”, “era”, “period” and “epoch”. In dealing with the great span of Earth's history the abbreviation “ma” is the convention used for “million years ago”.

The Hadean Eon (4,600-4,000 ma) saw the consolidation of stellar material to form Earth, which during this time was essentially a ball of molten rock. It was also during this time that Earth was hit by a large object that dislodged material that became the Moon.

In the Archean Eon (4,000-2,500 ma) three large crustal rock masses were formed in what is now Western Australia: the Yilgarn, Pilbara and Gawler Cratons. These, along with other rocks of the Canadian Shield and Greenland, are considered the oldest on Earth. At this time there was no land mass to the east of the cratons in what we would recognise today as eastern Australia.

During the Proterozoic (“Earlier Life”) Eon (2,500-545 ma) the three WA cratons fused, becoming the major portion of the Australian continent, but there still was no land mass for an “eastern Australia”. At this time the super-continent Gondwana was being assembled by the amalgamation of a western portion (South America and Africa) with an eastern portion (Antarctica and Australia). The atmosphere became oxygen rich during the mid part of this eon, and in its latter part many types of soft-bodied organisms evolved. Glaciations are known to have occurred in this timeframe.

We are currently in the Phanerozoic (“Visible Life”) Eon (542 ma-present), during which life on Earth became more complex for plants as well as animals. Within this eon, specifically during the Paleozoic Era (542-252 ma) the geologic framework for the southeast coast of Australia was set, in part by the hard metamorphic rocks in three of the five geological provinces recognised along the southeast: the Tweed-Richmond Basin, New England Fold Belt and Lachlan Fold Belt.

At the end of the Paleozoic Era (Permian Period, 299-252 ma) and at the beginning of the Mesozoic Era (Triassic Period, 252-201 ma) soft sedimentary rocks were laid down in a fourth province the Sydney Basin, in some cases overlying older rocks from parts of the Lachlan Fold Belt. The Eastern Highlands (running from Queensland through to Victoria) began to uplift, and a line of marine basins ran from Queensland to Tasmania, with the basins filled first by glacial sediments and then marine

Table 3.1.1. Geological time frames for the evolution of Australia from the creation of Earth 4.6 million years ago. Time intervals of particular relevance to the evolution and configuration of southeast Australian estuaries are bold. Events within the Quaternary (Pleistocene and Holocene Epochs) are set out in detail in the main body of the text. Divisions of geological time in the table are those of the International Commission on Stratigraphy (2013).

Eon	Era	Period	Epoch	Million Years	
Phanerozoic	Cenozoic	Quaternary	Holocene	last 11,700 years	
			Pleistocene	2.6–0.0117	
		Neogene*		23–2.6	
			Paleogene*		66–23
	Mesozoic	Cretaceous		145–66	
		Jurassic		201–145	
		Triassic		252–201	
	Palaeozoic	Permian		299–252	
		Carboniferous		359–299	
		Devonian		419–359	
Silurian			443–419		
Ordovician			485–443		
Cambrian			542–485		
Proterozoic				2,500–542	
Archean				4,000–2,500	
Hadean				4,600–4,000	

*The Paleogene and Neogene are sometimes known collectively as the Tertiary Period.

or terrestrial sediments including coal deposits. Volcanic activity was located along the line of marine basins.

During the mid Mesozoic (Jurassic Period, 201-145 ma), East Gondwana, comprised of Antarctica, Madagascar, India, and Australia began to break off from Africa via a rift that began in northwest WA. Separation of the southern coast of Australia from Antarctica also began, leading to the formation of the sedimentary basins of Gippsland. Sea floor spreading continued in a southerly direction along the WA coast and along the southern Australian coast during the Cretaceous Period (145-66 ma) leading to the separation of Australia from Antarctica. Global flooding divided Australia into three main landmasses, and extensive erosion that had begun in the Permian permitted overland flooding and sediment deposition. By the end of the period the sea had withdrawn but an extensive river system developed in the centre of the continent.

The general outline of the east coast of Australia was finalised in the Tertiary when soft sedimentary rocks laid down in the Mesozoic were joined by basaltic rocks to form the fifth province – the Clarence-Morton Basin.

The Eastern Highlands continued rising but a rift along the eastern margin of the continent spread from south to north allowing the creation firstly of the Tasman and then the Coral Sea. New Zealand migrated east.

Spreading along the rift took the original continental shelf of eastern Australia, leaving a narrow, steep shelf that has influenced wave and tide regimes to the present day, factors that impinge on the delivery of sand to the current shoreline, its movement on, off shore and alongshore including entrapment between headlands. The proximity of the rift to the highlands meant that east flowing rivers would be short and supply only low rates of sediment. Further, high energy waves sort and remove all fine

sediments and move the residual coarse material northward due to littoral drift.

Initially cooler than the Cretaceous Period, the early part of the Palaeogene Period (Paleocene Epoch, 56-23 ma) saw temperatures rise sharply with climate becoming warm and humid globally. The split from Antarctica was finalised, and the continent moved continually northward at the rate of five to six centimetres per year, experiencing only minor erosion and deposition.

The small connection between South

America and Antarctica let go in the Palaeogene, creating the Southern Ocean, allowing a circumpolar current, an event hypothesised as the trigger for permanent ice to build over Antarctica and influence Australia's weather patterns.

The Earth cooled into a series of ice ages during the Neogene (23-2.7 ma), and Australia became drier on its northward migration as it entered a zone of low rainfall. About 15 million years ago the distribution of snow and ice in the Southern Hemisphere began to assume its present form. With lowered sea level river valleys were deeply cut. When South America linked to North America 5 ma the Southern Ocean was the only global circulation.

Quaternary Period/Pleistocene Epoch

The Pleistocene Epoch (2.6 ma – 11,700 years ago) should be recognised as a time of cold, with repeated glacial-interglacial cycles and major changes in global sea levels. Some researchers have estimated there have been at least 11 cycles of rise and fall of sea level during the Pleistocene and the coastline of Australia would have been successively modified by repeated rises and falls of sea level as the ice ages came and went. Interglacial warm intervals such as the warm phase we are presently experiencing were relatively short events.

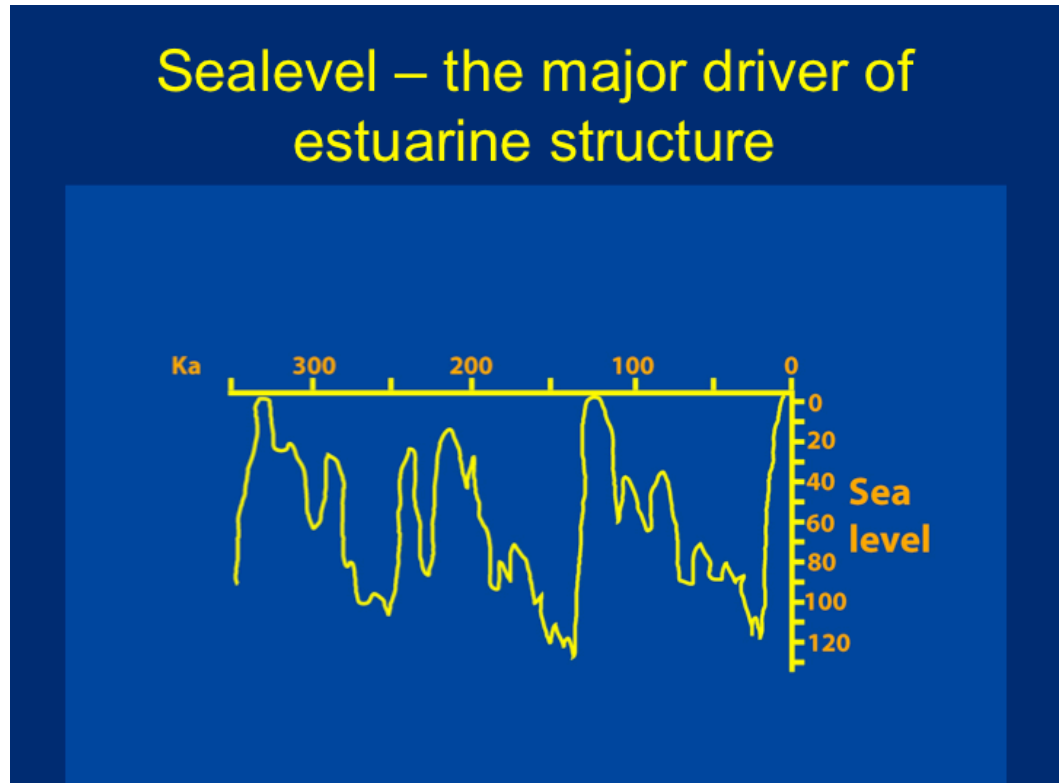


Figure 3.1.1. Sea level - the major driver of estuary structure (Adapted from Roy 1997, p. 6).

As polar ice caps expanded, ocean levels fell in the order of 100-130 m, permanent snow and ice covered the higher peaks in Alpine Australia and Tasmania. (Ice sheets up to 3,000 metres covered much of North America and Europe during these intervals.) When ocean levels fell and shorelines receded, rivers along the southeast coast extended to meet the sea 20-30 km further to the east than at present. Lasting tens of thousands of years, flood plains were eroded and river valleys excavated to meet the lowered base levels.

Throughout the Pleistocene Epoch the eastward extent of individual catchments and the drainage patterns in the lower parts of estuaries would have varied at each interglacial interval, contingent on the height to which sea level rose. Studies indicate that during past interglacial events sea level has been meters higher than it is at present (Murray-Wallace 2007).

The last period of falling sea level began about 105,000 years ago and continued for 80,000 years, during which flood plains and river valleys were eroded, wetlands disappeared, and the southeast coast moved further offshore. About 18,000 years ago a climate reversal melted the ice caps and sea level again began to rise, ushering in the Holocene Epoch. The mouths of the river valleys were again inundated and the coastline we know today was set to emerge.

Quaternary Period/ Holocene Epoch: 11,700 years ago to the present

Although sea level reached its current position about 6,000 years ago, it did not rise at a uniform rate; more specifically, there were irregular and geologically rapid pulses (e.g. Gornitz 2009). Further, it was slightly higher before falling to its present level (Lewis *et al.* 2013). Nevertheless, with sea level stabilised, the eastward extent of individual catchments was established, with the orientation of the entrances to some estuaries being determined by headlands or islands. Hundreds of beaches (721 in NSW, Short 1993) fronted, and over 1,000 water bodies (950 in NSW, Williams *et al.* 1998), most of them ephemeral, drained to the Tasman Sea.

The internal structure of estuaries along the southeast coast has been characterised in terms of four geomorphological zones (Roy 1984). At the most upstream end of the estuary, where catchment-derived sediments are deposited and create a flood plain, is the narrow and shallow Riverine Channel. The rate at which fluvial deposition occurred here and further downstream is dependant on catchment size, rainfall, and rock type (Bird 1976). The Fluvial Delta is located where the channel enters the main portion of the estuary, and recent examination of its configuration has shown some unusual structural features (Mesley 2003). The delta drops off into the deepest part of the estuary, the Central Mud Basin, a relic of the old river valley at the time of low sea level. As sea level rose it brought sediment onshore, leaving a plug of marine sand, the Marine Tidal Delta at estuarine entrances. This is why in a number of southeast Australian estuaries the depth at the entrance is shallower than upstream. With a stable sea level there would be no driving force to move the tidal

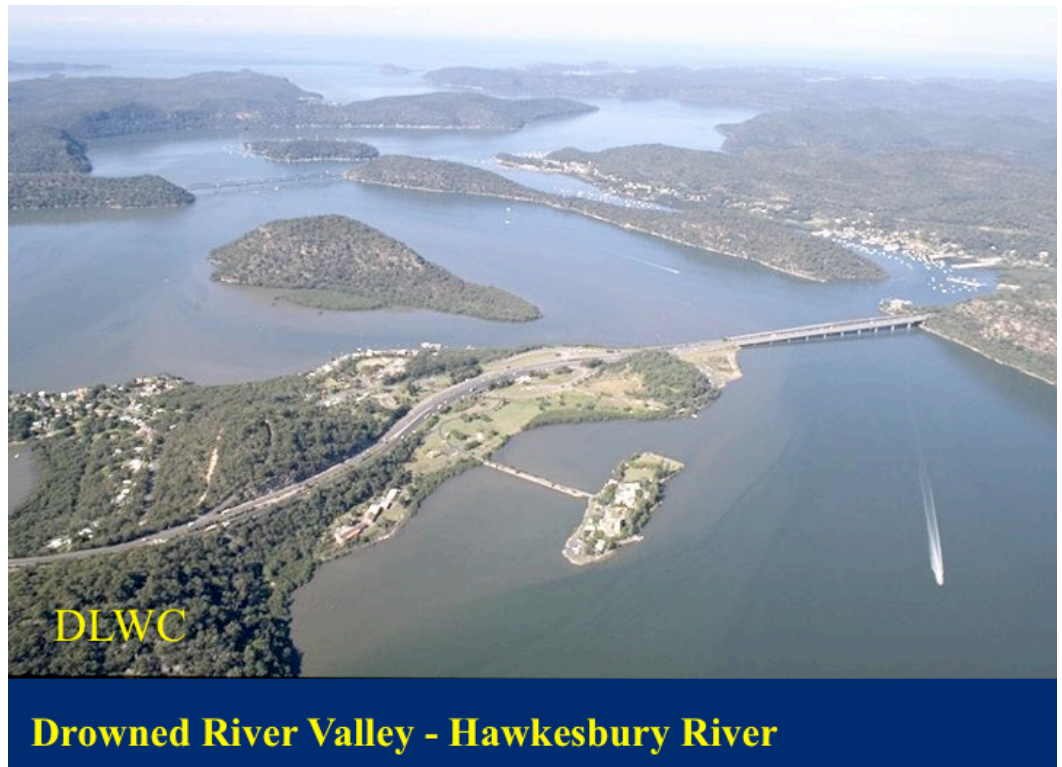


Figure 3.1.2. Drowned River Valley, Hawkesbury River, NSW (DLWC 2000).

delta further into the estuary but its surface could change, being altered by storm waves or flood channels.

Oceanic material swept into the mouths of estuaries has a distinctly different sedimentary structure to the fluvial material found upstream. Marine sediments are in most cases comprised of rounded (having been extensively reworked by ocean waves) quartz grains and a large proportion of calcareous material derived from the shells of molluscs living on the ocean floor. Fluvial sediments are characterised by silts and the angularity of hard rock fragments.

In some cases, where catchments were comprised of hard rock that had been successively incised during glacial periods, steep-sided river valleys were drowned as sea level rose. The Parramatta River-Sydney Harbour estuary and other river valleys within the Hawkesbury Sandstone of the Sydney metropolitan region are this kind of drowned system. Figure 3.1.2 shows an example. Estuaries of this type would have changed little in their configuration over successive glacial episodes, contingent on water level at the end of each interglacial interval. Because of topography there is little development of flood plains in drowned river valleys.

In low relief catchments where longshore drift caused by ocean swell and/or wind waves pushed sedimentary barriers across the front of a broad river valley a different type of estuary was formed – the barrier estuary. Figure 3.1.3 contains an example of a Barrier Estuary. A bar was built and the waters behind took on a lake or lagoonal configuration. Over time, enough catchment-derived sediment was deposited to generate flood plains. Catchment situations can be realised from Figures 3.1.4, 3.1.5 and 3.1.6.

Where catchments are small and runoff is limited, some estuaries can not maintain a permanent entrance, being only open to the sea when rainfall raises water behind the enclosing berm to the level where the berm is broken and oceanic flushing is initiated. The time over which the entrance remains open is variable, depending on catchment size, amount of rainfall and runoff, and longshore currents that refill the entrance with sand. The largest intermittent estuary in NSW is Smiths Lake (Figure 3.1.7), and

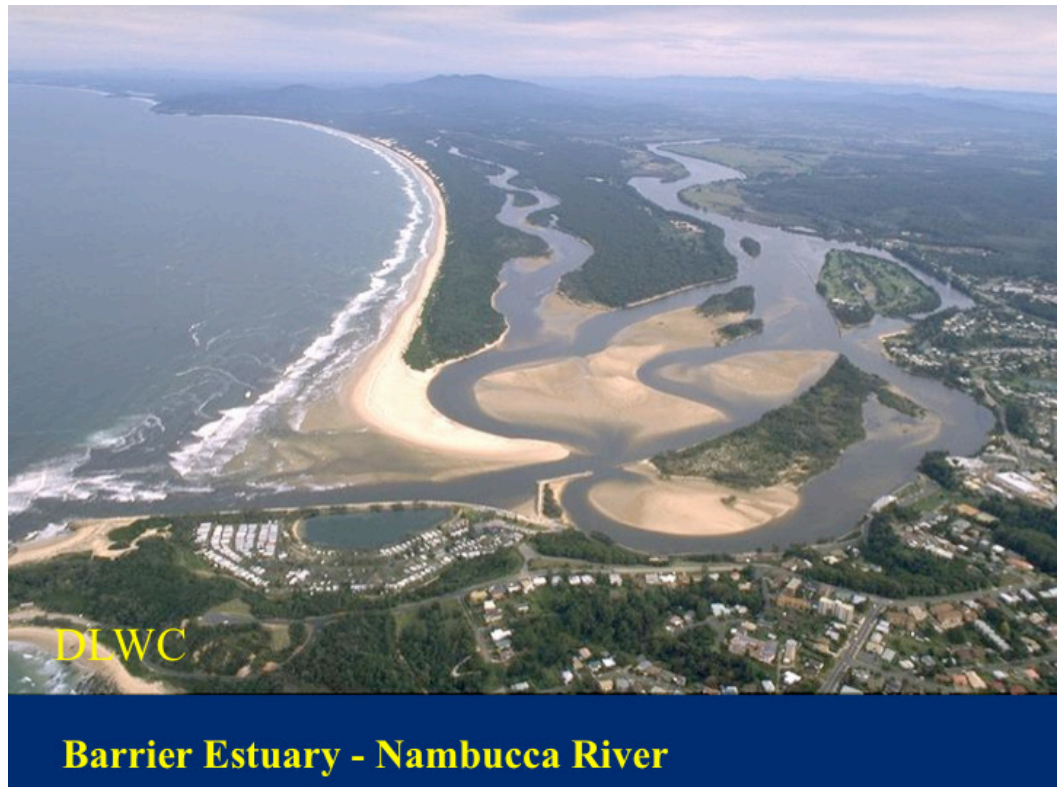


Figure 3.1.3. Barrier Estuary, Nambucca River, NSW (DLWC 2000).

Marine infilling – one major driver of estuary evolution



Figure 3.1.4. Catchment infilling - a major driver of estuary evolution: marine component (DLWC 2000).

the Gippsland Lakes were intermittent in their behaviour until permanent entrances were placed to facilitate navigation.

Estuarine Evolution and Ecology

The fact that catchment derived sediments fall out of suspension at the Fluvial Delta as well as further downstream, and that the Marine Tidal Delta helps create a trap for these particles, produces a situation that allows progressive infilling of the Central Mud Basin (Roy and Thom 1981, Roy 1984; Figure 3.1.8). Over time and contingent on sediment yield some basins have infilled completely, creating a uniform depth down to the entrance. This maturing process is seen in the Hawkesbury River where the large size of the catchment (22,000 km²) and readily eroded sediment (sandstone) have filled the main river channel down to Broken Bay. In contrast, at adjacent Pittwater where the catchment is miniscule (50 km²) and the fluvial input of sediments is negligible, virtually the whole of the estuary remains a basin. The difference in shape between these adjacent drowned river valleys is a good example of the concept of estuarine evolution, or maturing.

In contrast to the drowned river valleys, the infilling of barrier estuaries involves a distinctly different set of maturing circumstances. Maturing of barrier

Terrestrial infilling – another major driver of estuary evolution



Figure 3.1.5. Catchment filling - a major driver of estuary evolution: terrestrial component (DLWC 2000).

Estuary evolution since sealevel stabilised 6,500 years ago – Catchment infilling

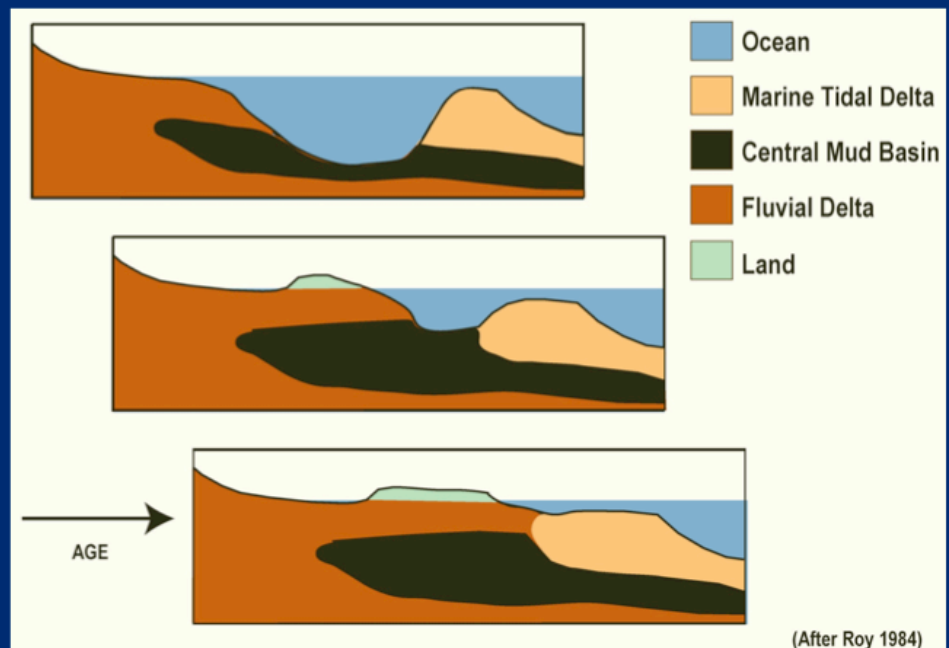


Figure 3.1.6. Schematic of catchment infilling - a major driver of estuary evolution (Roy 1984).

estuaries, as well as showing a gradual shallowing of the basin, also proceeds by reducing the surface area of the enclosed waters. Over time what was seen as a broad lagoon or lake-like expanse of



Figure 3.1.7. ICOLL/IOCLL, Smiths Lake, NSW (DLWC 2000).

Examples of geomorphic evolution of NSW estuaries

	Drowned river valley	Barrier estuary
Infant	Pittwater	Lake Macquarie
Adolescent	Parramatta R.	Wallis Lake
Adult	Georges R.	Hunter R.
Pensioner	Hawkesbury R.	Hastings R.

(after Roy *et al.* 2001)

Figure 3.1.8. Examples of geomorphic evolution of NSW estuaries (Roy *et al.* 2001).

water becomes more river-like in its configuration. Lake Macquarie is an example of an immature barrier estuary; it is deep (22m) and broad, while

small cover of mangrove and saltmarsh compared to mature systems such as the Brisbane, Richmond

the Richmond and Shoalhaven Rivers are now so infilled that all that remains of the original shape are residual flood plains and swamps. The Clarence River is in an intermediary stage; relics of the original broad shape are seen in the Broadwater and Lake Wooloweyah.

The fact that estuaries evolve has ecological implications, particularly for tidal ranges in wetlands. Dimensions of an entrance channel control the volume of water entering an estuary on a rising tide, and where the upstream basin is large, or lake-like, the tide range can be quite small. In Lake Macquarie tidal range is of the order of 100mm even though in the adjacent ocean the range can be up to 2m. When an immature barrier estuary loses its lake-like shape as it infills and matures, the same tidal input, now constrained to a narrowed river channel, is translated upstream. This also means that tidal range increases along the channel and more foreshore habitat is inundated. This is the reason why coastal lakes such as Lake Macquarie and Wallis Lake have a relatively

and Shoalhaven Rivers or to intermediary rivers like the Clarence that are still evolving along the evolutionary continuum.

Intermittent estuaries are curious creatures: some are more open than closed, and for others the reverse is the case (Haynes 2004). This phenomenon is presumably related to rainfall, with the estuary tending to remain open when catchment runoff is high. Hence the El Nino Southern Oscillation Index (ENSO) has value in forecasting when intermittent estuaries will be mostly closed (El Nino – dry weather conditions) or mostly open (La Nina – wet weather conditions).

Some intermittent estuaries are opened artificially, when a bench mark set to protect local property or infrastructure is reached, rather than being allowed to open under a natural set of conditions. Where features such as foreshore septic systems or roadways are relocated, filling can reach higher levels, promoting more extensive scouring of the entrance on breakout and sustaining the opening and flushing for a longer interval.

An issue that would benefit from further study is the differentiation between the barrier estuaries and the intermittent estuaries. While these categories of estuary appear in some ways distinct from one another, an examination of archival material shows that some large barrier estuaries have been closed for lengthy periods in the past. Wallis Lake is an example:

“[(Text line 1672). Inquiry by Commissioner Stephen.] Is the (Wallis) lake closed at any season of the year? (Response by Mr. H. Woodward) It is never open. It is totally closed up, and there is bush growing between it and the sea. I think there is about 120 yards of land between it and the sea.” (Select Committee 1889)

Wallis Lake is now permanently open to the sea due to training walls and breakwaters, as are other estuaries known to have been intermittent in their opening characteristics (e.g. Lake Macquarie, Lake Illawarra, Wagonga Inlet). Dredging has taken place at the entrances of other estuaries (e.g. Tuggerah Lakes) to encourage water circulation.

The placement of breakwaters has been shown to enhance tidal velocity to the degree that scouring of the channel bed takes place. At Wallis Lake the abutments of the Forster-Tuncurry Bridge were threatened by channel scour (Nielsen and Gordon 2008). Wetland habitat such as seagrass, mangrove and saltmarsh may also be at risk from channel scour. Another feature of breakwater emplacement

is the raising of high tide and lowering of low tide, the effect of which on wetland communities is little studied but might be expected to allow saltmarsh and mangrove to migrate upslope and upstream contingent on topography and/or infrastructure.

As well as coastal lakes, many southeast coast rivers (e.g. Brisbane, Richmond, Clarence) have had their entrances manipulated to facilitate navigation. Lengthy training walls have significantly reduced shallow foreshore vegetated habitats.

The nature of estuarine wetlands is determined in the first instance by shoreline geomorphology. Macro algae can be abundant in drowned river valleys as they adhere to rock substrata, but the steep sides of this type of estuary prohibits extensive settlement of seagrass, mangrove, saltmarsh and terrestrial wetlands. A much different situation arises in barrier estuaries where, due progressive development of low relief flood plains with abundant soft sediments there can be extensive colonisation by seagrass, mangrove, saltmarsh, She-oak and Casuarina. The intermittent estuaries, due to their irregular opening and closing regimes are sometimes devoid of seagrass and mangrove, but often have fringing patches of saltmarsh, She-oak and Casuarina.

That estuarine shorelines will be inundated as sea level rises and existing wetlands will be submerged has been recognised for some time (Vanderzee 1988; Williams 1990; Hughes 2003). For saltmarsh any rise in level of the ocean will be especially critical (NSW Scientific Committee 2004; Laedgsgaard 2006; Laedgsgaard *et al.* 2008). A rise of sea level of 100mm along the southeastern Australian coast has revealed itself in the 100 years of tidal records kept at Fort Denison (Watson 2011), and such measurements will be complimented with determination of global mean sea level by advanced technologies such as satellite altimeters (CSIRO on line).

Numerous other factors influence the distribution of estuarine wetlands and the assemblage of species therein (see Chapters 3.4, 3.5 and 3.8) but an important phenomenon is their base elevation, with the depth of water over wetlands being determined by long term rainfall patterns and other factors (Rogers *et al.* 2005).

Studies based on historical aerial photographs show that large changes in macrophyte cover have occurred in a number of estuaries (McLoughlin 1987, 2000; Mitchell and Adam 1989; Thorogood 1985; Saintilan and Williams 1999, 2000; Williams and Meehan 2004; Williams and Thiebaud 2007;

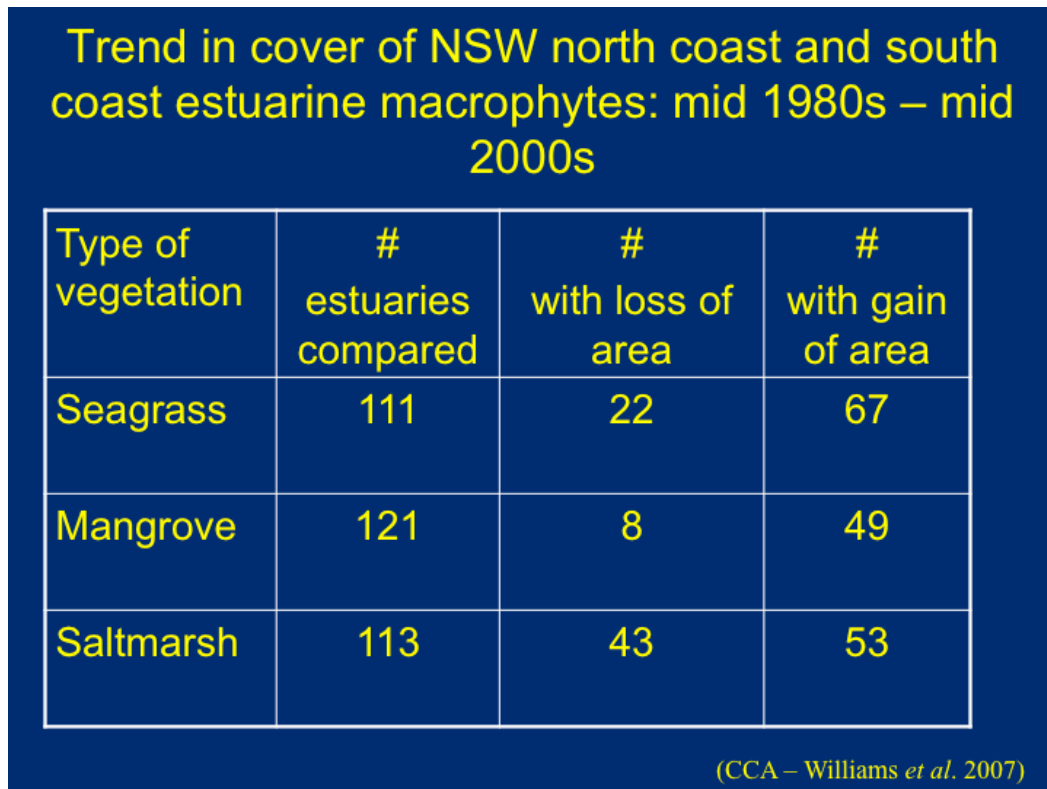


Figure 3.1.9. Trend in cover of NSW north coast and south coast estuarine macrophytes: mid 1980s–mid 2000s.

Burrell 2012). A number of other studies can serve as baselines against which to assess change in macrophyte cover (West *et al.* 1985; Yassini 1985; Clarke 1993, 1994; Adam 1996; Williams and Watford 1997; Wilton 1998; Williams and Watford 1999; Wilton *et al.* 2003; Pickthall *et al.* 2004; West *et al.* 2004). More information is needed on how estuarine habitats in southeast Australia change over time, and the circumstances that drive these changes.

The past two decades have seen continuous advancements in the methods by which estuarine wetlands and in particular the cover of macrophytes has been determined (Chapter 5.5). Figure 3.1.9 provides a snapshot of the results of surveys of the extent of selected estuarine macrophytes for NSW. Analogue mapping techniques (e.g. transfer scopes) have been replaced with digital procedures, the latter involving creation of images from historical aerial photos or directly from a new generation of airborne cameras, and the use of geographic information systems to assess these images. Old style baseline maps have qualitative value as indicators of places where large changes have taken place and fine-scale measurements might be needed (Meehan *et al.* 2005). In some instances studies have been undertaken to reanalyse historical photos with digital techniques (Williams and Meehan 2004; Burrell 2012). In

addition, other remote sensing methods using satellites are being developed to determine the extent, and perhaps ultimately, the health of estuarine macrophytes (Anstee *et al.* 2009).

Recent presentations (Watson and Frazer 2009; Green Cross online) suggest the human community living adjacent to estuarine wetlands will need to adapt to rise in sea level. At the very least, foreshore settlements as well as transport facilities will need to be modified or relocated.

The high density of human population

along the southeast coast has in many cases damaged estuarine habitats such that rehabilitation works are underway (e.g. Kooragang Wetland Rehabilitation Project) or are being actively planned. In each instance the physical characteristics of an existing or proposed wetland site need to be well understood and tailored to the biological needs of species that are to be transplanted or otherwise relocated (Mitsch 2000). These physical characteristics include among other things the characteristics, history and future of estuaries and their shorelines.

Conclusions

While the major portion of the Australian continent is incredibly old, the eastern portion is relatively young.

The outline of the eastern coast emerged 80-65 million years ago with seafloor spreading.

During the Pleistocene and Holocene Epochs (the last 2.6 million years) the southeast coast has migrated in an easterly direction by tens of kilometres on multiple occasions as sea level has dropped by up to 130m. Estuarine wetlands have moved eastward under these conditions.

Sea level has been somewhat higher in past inter-glacial cycles than at present, a feature that would also modify the extent and location of estuarine wetlands.

Sea level rose from its low point about 18,000 years ago to its present height about 6,500 years ago at which time a new series of wetlands were created. Some of these wetlands would have disappeared as estuaries matured naturally or were modified by engineering projects. Other wetlands would have been newly created as estuaries matured.

Water level recorders at Fort Denison show an increase in sea level over the past 100 years that is expected to continue and will alter estuarine shorelines to varying degrees. Drowned river valleys will change little due to their topography, but the low relief of barrier estuaries and intermittent estuaries will experience extensive inundation that will modify the distribution and extent of wetlands.

Acknowledgements

Peter Roy provided considerable support during this geological and geomorphological endeavour. Errors of fact arise from my own ignorance or oversight.

Suggested Reading

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