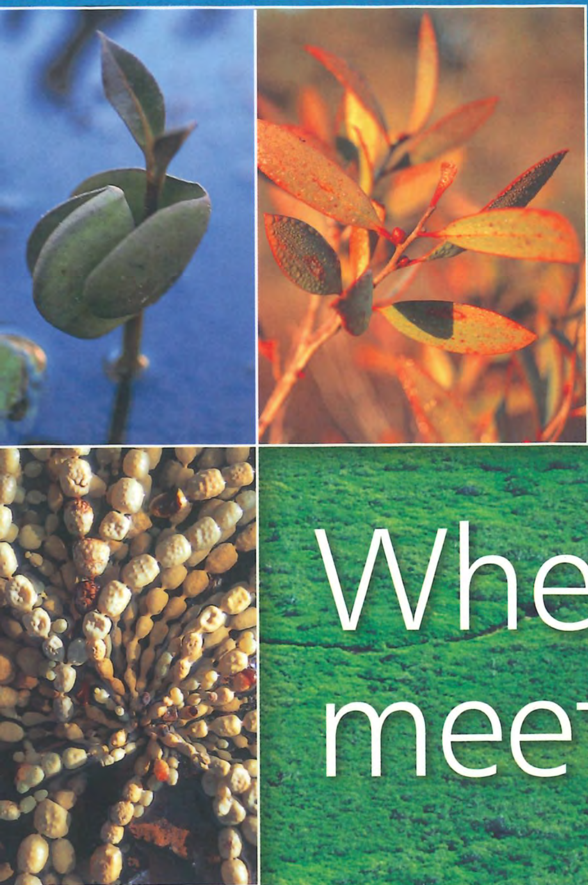

Where river meets sea

Exploring Australia's estuaries

Where river meets sea:
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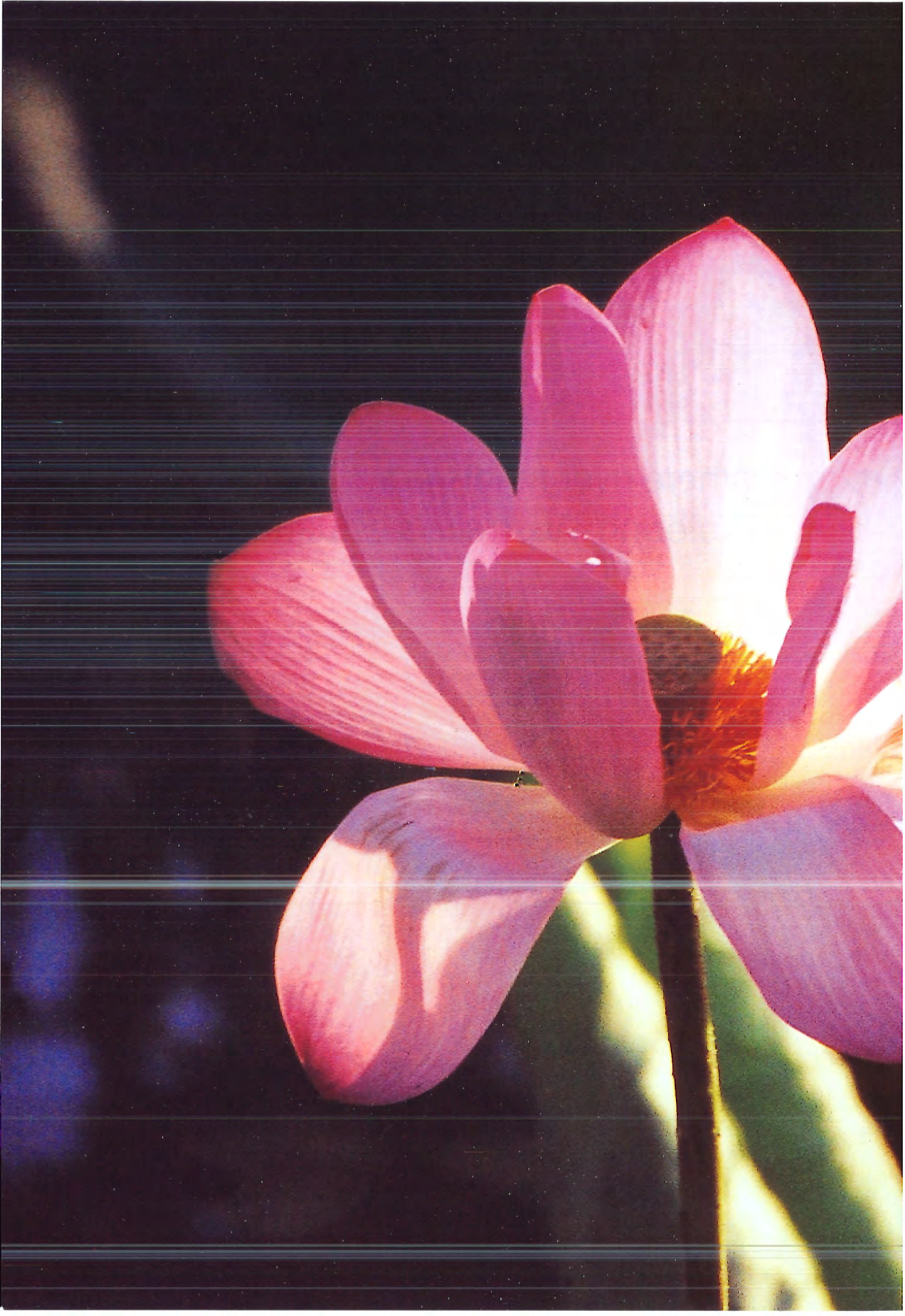

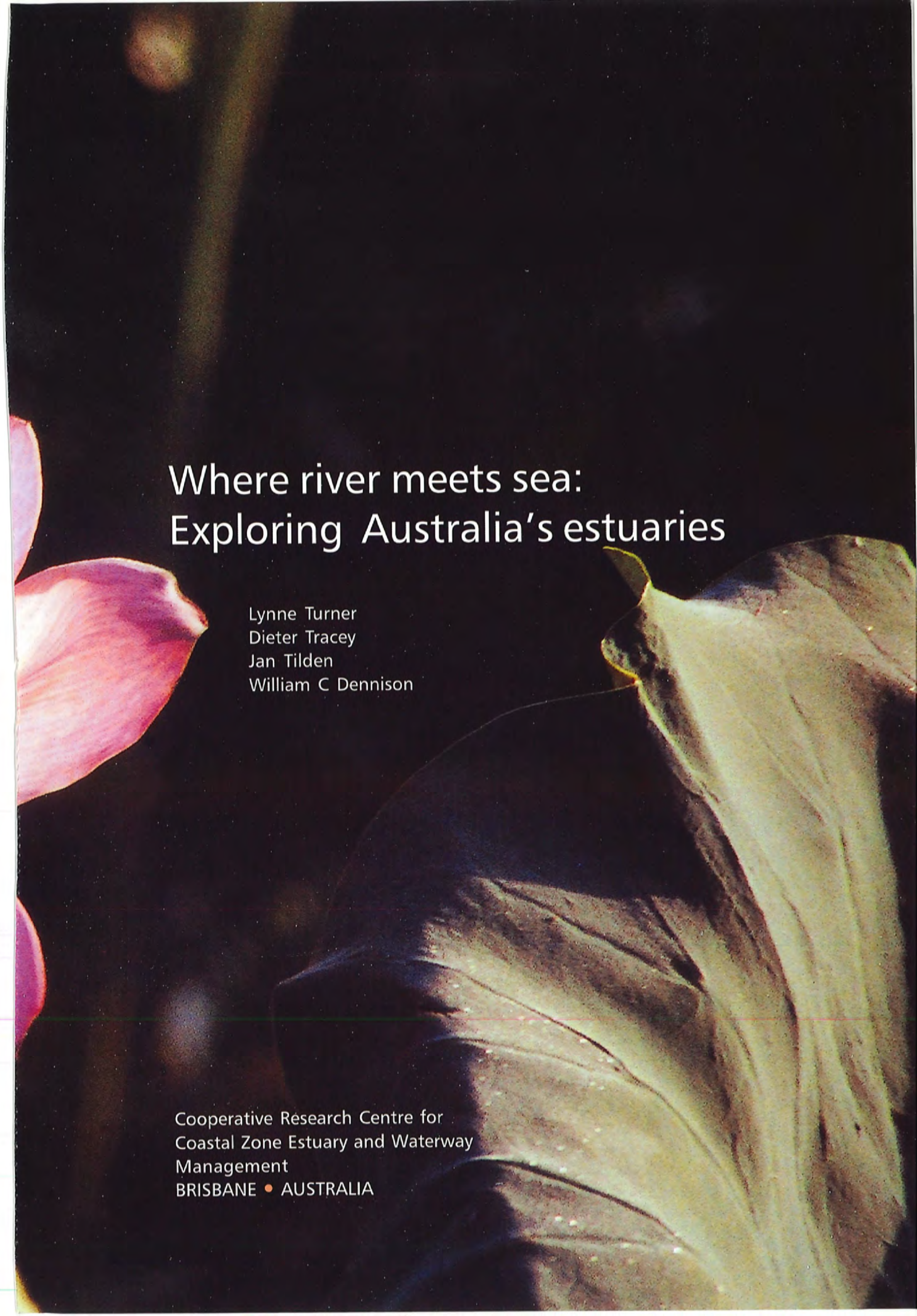

Where river meets sea: Exploring Australia's estuaries

Lynne Turner
Dieter Tracey
Jan Tilden
William C Dennison

Cooperative Research Centre for Coastal Zone Estuary and Waterway Management
BRISBANE • AUSTRALIA

Where river meets sea: Exploring Australia's estuaries

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Published by the Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management (Coastal CRC)

Indooroopilly Sciences Centre
80 Meiers Road
Indooroopilly Qld 4068
Australia
www.coastal.crc.org.au

Printed by Graphic Skills, Maroochydore, Qld

National Library of Australia Cataloguing-in-Publication data
Where river meets sea: Exploring Australia's estuaries
ISBN 0 9578678 8 3

Preface

Exploring Australia's estuaries

Australia has over 1000 estuaries, each a special and dynamic system. Just over half of Australia's estuaries remain in near-pristine condition. Most of these are smaller tidal systems along the far northern coastline. The majority of larger river systems and most estuaries associated with population centres have been degraded by human activities. Decisions about the use and management of our estuaries are made every day at a local level. This handbook aims to enhance estuary literacy among Australians, building our knowledge and interest in championing the cause of estuary protection and management. Importantly, this book hopes to dispel the myth of the 'away' place. What runs off our catchments, flows through our rivers and is flushed down drains from our everyday activities ends up in our estuaries. The challenge is to do whatever we can in our everyday activities to protect the health of the estuaries where we live, work and play.

Using this book

A general introduction to estuaries is offered in Chapter 1. This chapter discusses the different types of estuaries and the processes that drive them. It is important to understand how an estuary works if it is to be effectively managed.

Estuary management is not a case of one size fits all. The diversity of Australian estuaries is covered in Chapter 2 with a regional overview of the management issues affecting Australia's estuaries.

Estuarine habitats are extremely productive and are important socially, economically and ecologically. Chapter 3 provides an overview of the major habitat types within Australian estuaries.

The way we use and value estuaries is reflected in estuary health. Chapter 4 discusses a range of beneficial uses that rely on estuaries and the impact they can have on estuary health. These uses need to be carefully managed to ensure estuarine health is not irreversibly compromised. The chapter also explores current thinking on appropriate responses to the challenges of estuary management.

Chapter 5 deals with some of the approaches and challenges in determining the 'health' of estuaries around the world and discusses the health of Australia's estuaries.

Chapters 6 to 12 explore Australian estuaries state by state. For those keen to 'get into' estuaries, these chapters can be used as a guide to what you will find.

Chapter 13 includes lessons of estuary manangement from overseas case studies. This chapter also looks at what we must do to ensure healthy Australian estuaries.

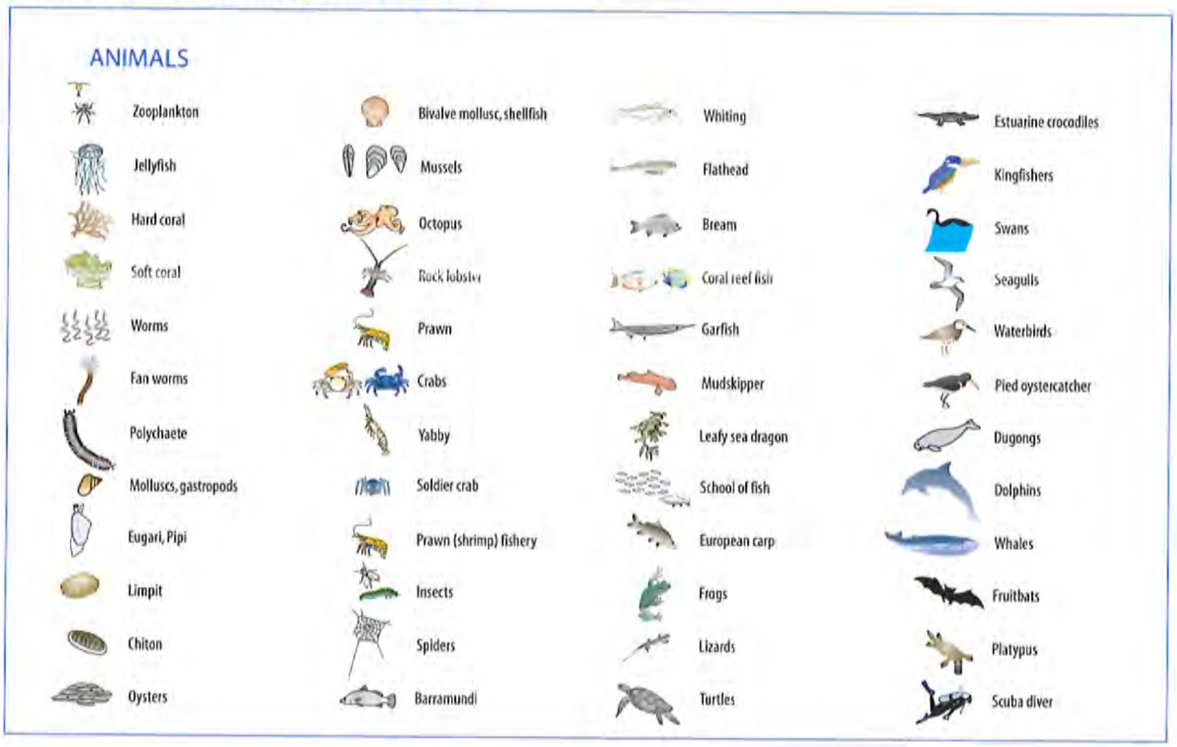
Chapter 14 identifies a number of groups, contacts and resources across Australia supporting estuary management.

Conceptual diagrams

Conceptual diagrams are used throughout this book to summarise major components and processes in estuaries. These diagrams use simple graphic elements to illustrate the important physical, chemical and biological processes in an estuarine ecosystem. The diagrams are generally designed to reflect major system interactions. In one visual framework, they combine observed phenomena with the best knowledge or understanding available, making it easier to see what connections may exist among various known factors influencing estuarine health.

By undertaking the construction of a conceptual diagram, any gaps in our knowledge, or the clarity of understanding, are identified, so these diagrams are helpful in determining research needs. They are also useful for assessing the strengths or weaknesses in a given management approach or proposal. A key to conceptual diagram symbols used throughout the book is given below. Symbols are freely available from the websites of the Coastal CRC and the Integration and Application Network, University of Maryland, USA.

Symbols used in conceptual diagrams



PLANTS

- Rainforest
- Dry (eucalypt) forest or woodland
- Ti-tree (*Melaleuca*) wetlands
- Mangroves, *Avicennia marina*
- Mangroves, *Rhizophora stylosa*
- Mangroves, *Brugeria gymnorrhiza*
- Mangroves, *Ceriops australis*
- Diverse mangrove forests
- Ferns
- Reeds
- Saltmarsh
- Waterlilies
- Seagrass
- Deep water seagrass
- Shallow water seagrass
- *Halophila*
- *Zostera*
- *Amphibolus*
- *Posidonia*
- *Cymodocea*
- *Halodule*
- *Heterozostera*
- Detritus
- Kelp
- Green macroalgae
- Red macroalgae
- *Halimeda*
- *Caulerpa*
- Benthic microalgae
- Phytoplankton
- Algal blooms - cyanobacteria
- Dinoflagellates

INDUSTRY/RESOURCE USE

- Beef cattle grazing
- Agriculture - cropping
- Dairying
- Agriculture (sugar cane)
- Dryland agriculture (wheat)
- Viticulture
- Plantation forestry
- Aquaculture (shrimp ponds)
- Aquaculture (cages)
- Oyster racks
- Trawling
- Recreational boating
- Recreational fishing
- Safari tourism
- Ports and shipping
- Saltworks
- Offshore oil rig
- Land clearing
- Mining
- Impoundments
- Sewage treatment plant
- Major urban centres
- Small urban centres
- Industry
- Old industry
- Churches
- Power plant

PROCESSES

- Rainfall
- Cyclones
- Toxicants
- Seagrass loss
- Introduced pest species
- Pathogens
- Temperature extremes
- Pulsed run-off events
- Groundwater
- Acid sulfate run-off
- Deposition and scouring
- Sediment resuspension
- Deposition and burial
- Sediment nutrient fluxes
- Tide range
- Ocean flushing
- Ocean upwellings
- Iron ore dust
- Burial
- Dessication
- Groundwater
- Run-off
- Stormwater
- Fixation
- Denitrification
- High/low nitrogen, phosphorus
- Salinity extremes
- Limitations, phosphorus, nitrogen

MANAGEMENT ARRANGEMENTS

- International obligations and treaties
- State level planning initiatives
- Regional level initiatives
- Indigenous management
- Port authorities
- Defense force lands
- Poorly understood systems

Acknowledgements

This book presents the work undertaken by the Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management and its partners as part of the National Land and Water Resources Audit's National Estuary Assessment. This work was funded by the National Land and Water Resources Audit, the Fisheries Research and Development Corporation and the Coastal CRC.

We would like to acknowledge the contribution of those involved in the estuary assessment project of the Australian Catchment River and Estuary Assessment, 2002:

Lynne Turner (Principal Investigator), Roger Shaw, Dieter Tracey, Jimaima LeGrand, Jackie Robinson, Kerry Rosenthal (Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management); David Heggie, David Ryan, Andrew Heap, Jonathon Root, David Fredericks, Peter Harris, Suzanne Edgecombe, Sonya Bryce, Craig Smith, Lynda Radke, Domenic Rositano, Michelle DePlater (Geoscience Australia); John Parslow, Mark Baird, Jason Waring, Brett Wallace, Stephen Walker, Pavel Sakov (CSIRO Marine Research); Richard Davis, Ian Webster (CSIRO Land and Water); William C. Dennison, Eva Abal, Paul Greenfield (The University of Queensland); Simon Townsend, Armando Padavan (Department of Infrastructure Planning and Environment, Northern Territory); David Robinson, Andrew Moss, Jonathan Hodge, Chris Pattearson (Environmental Protection Agency, Queensland); Malcolm Dunning, Maria Bavins (Queensland Department of Primary Industries and Fisheries); David Miller, Bruce Coates, Justin Meleo (Department of Infrastructure Planning and Natural Resources, New South Wales); Andrew Steven, Anthony Boxshall, Vicky Barmby (Environmental Protection Authority, Victoria); Gwen Fenton, Ray Murphy (Department of Primary Industries, Water and Environment, Tasmania); Patricia von Baumgarten, David Turner, Liz Barnett (Department for Environment and Heritage, South Australia); Malcolm Robb, Zoe Goss, John Argus, Sam Nelson (Water and Rivers Commission, Western Australia); Patrick Hone, Kylie Paulsen and Peter Dundas-Smith (Fisheries Research and Development Corporation); Colin Creighton, Jim Tait, Rochelle Lawson (National Land and Water Resources Audit); Gina Newton and Jenny Boshier (Department of Environment and Heritage).

For their part in the preparation of this book we would like to thank:

David Scheltinga, Regina Counihan, Paul Pinjuh (Coastal CRC); Tiffany Inglis (Department for Environment and Heritage, South Australia); Colleen Foelz; Loraine Chapman; Graeme Harrington (Department of Primary Industries Water and Environment, Tasmania); Paul Candlin (Environmental Protection Agency, Queensland); Graphic Skills, Maroochydore.

Photographic acknowledgements

This book would not have been possible without the generosity of the many individuals and agencies who supplied photographs mostly at no cost to the Coastal CRC. These photographic contributors are listed here. A full list of photo credits is on page 277.

Robyn Adams; Don Alcock, Coastal CRC; Dr Anthony Boxshall; Simon Bryars, South Australian Research and Development Institute; Conservation and Land Management, Western Australia; Greg Calvert; Dr Tim Carruthers; Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management; Catherine Collier; Cooperative Research Centre for Freshwater Ecology; Dr Regina Counihan, Coastal CRC; CSIRO; Dane Davison-Lee; Dr Norm Duke, The University of Queensland; Department of Infrastructure, Planning and Natural Resources, New South Wales; Department of Natural Resources and Environment, Victoria; Department of Primary Industries Water and Environment, Tasmania; Environmental Protection Agency, Queensland; David Fairclough; Nick Fewster; Great Lakes Council, New South Wales; Great Lakes Environmental Research Laboratory, USA; Greening Australia ACT and South East NSW Inc.; William Haddrill; Tom Hearn; Hunter Valley Wine Country Tourism; Chris and Russell Lee, R.L. Avaiation, King Island; Lochman Transparencies; Mapland, Department for Environment and Heritage, South Australia; Mineral Policy Institute, New South Wales; National Aeronautics and Space Administration, USA; National Land and Water Resources Audit; Northern Territory Government; Onkaparinga Waterwatch Network; Robert Packett, Coastal CRC; Pelusey Photography; Queensland Department of Primary Industries and Fisheries; Queensland Government; Queensland Herbarium, Environmental Protection Agency; Queensland Natural Resources, Mines and Energy; Lynn Roberts; Chris Roelfsema; Dr Roger Shaw, Coastal CRC; W. Eugene Smith; Duncan Souter; Dr Jonathon Staunton-Smith; Jim Tait; Dr Jan Tilden, Coastal CRC; Dieter Tracey; Lynne Turner, Environmental Protection Agency; United States Geological Survey; Water and Rivers Commission, Western Australia.

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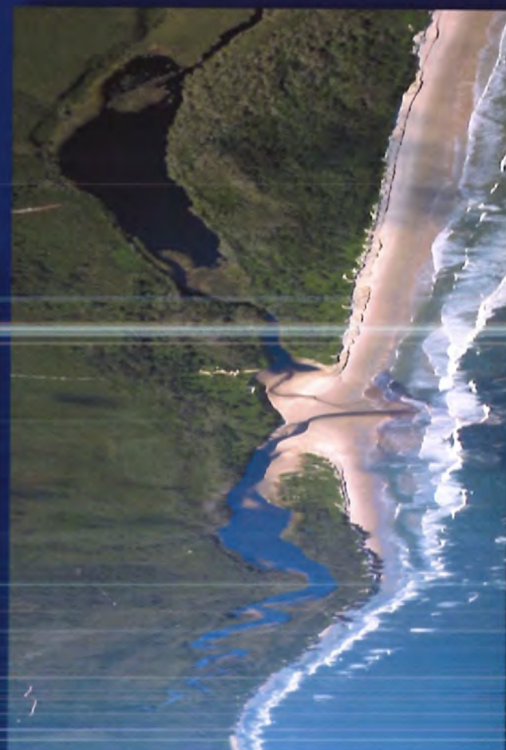
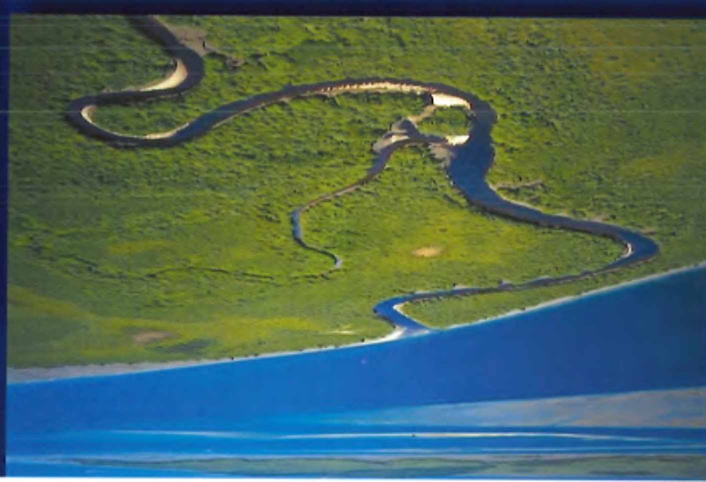
The coastline of Australia has not always been where it is today. During the last ice age, much of the water now in the world's oceans was locked up in polar ice caps and, consequently, the land surface of our continent was much larger. As the ice age came to an end, the water rose rapidly (by geological standards). By the time this process finished – about 6000 years ago – Australia had a new coastline.

The evolution of our estuaries, as we know them today, began at this time.



chapter 1

What is an estuary?

An estuary is a place where land and sea meet. It is a transition zone where water flowing off the surface of the land meets the regular ebb and flood of the tides. Surrounding mainland features or barrier islands help block freshwater flows and create a fertile mixing zone where organic and mineral nutrients from the land and sea accumulate.

Australian estuaries reflect the climatic extremes of our island continent. Freshwater flows are often ephemeral or non-existent and estuaries can be saltier than the sea. However, when floods arrive they can flow fresh to the mouth and beyond.

Estuaries are forever changing as they fill with sediment from the land and sea. Most of Australia's estuaries began their development about 6000 years ago at the end of the last ice age. Rising sea levels flooded coastal features such as river valleys.

Great variation in the shape of the coastline, climate and types of rivers have led to the formation of many different types of estuary, reflected in the names we give them – Port Phillip Bay, Manly Lagoon, Wilson Inlet, Wellstead Estuary, Pumicestone Passage, d'Entrecasteaux Channel, Lake Macquarie, Port Jackson, Tallebudgera Creek, Broad Sound, Great Sandy Strait, Darwin Harbour – these have all formed in places where fresh and salt water meet.

Estuaries are unique environments that include some of the most biologically productive ecosystems on Earth. They provide sheltered habitat, nursery and spawning areas for fish, crabs, prawns and shellfish. They help to filter pollutants, act as buffers to protect shorelines from erosion and flooding and provide essential food and habitat for birds, fish and other wildlife.

Estuaries and people

In Australia, the relationship between estuaries and people has evolved over many thousands of years. Before European settlement, Indigenous Australians living by the sea depended on these coastal waterways as a rich source of food. Today, Indigenous communities in coastal areas retain this close connection with the waterways that nourish their lands.

The first Europeans brought a maritime perspective to the relationship between people and estuaries. Typically they chose the most sheltered parts of coastal waterways to settle – places that offered the safest moorings for their ships. Then they turned their backs on the ocean and began developing the land upstream.

Soon, instead of our boats washing in with the tide, our wastes began to wash out. Estuaries were valued as channels to flush away things we didn't want to live with (such as sewage and factory waste). However, the sheltered bays and coves which had protected our fleets so well, also turned out to be ideal places for accumulating water-borne pollution. In highly populated areas, estuary health was compromised as a result.

More recently, we have begun to view estuaries as the complex living systems that they are. We understand that they can be healthy or unhealthy depending on how we treat them. And we are learning more and more about the value of healthy estuaries. Coastal waterways are an important part of our culture and our economy. They are also vital natural environments. Most estuaries provide sheltered living places, nurseries and spawning areas for wildlife including important commercial species. They help to filter pollutants and act as buffers to protect shores from erosion and flooding. They also provide food for birds fish and other wildlife.

Australian estuaries and our impact on them – some statistics:

- *86% of Australians live within 50km of the coast and 25% live within 3km, yet 70% of Australia's 32,000km coastline is sparsely populated*
- *a number of coastal regions are experiencing rapid urban development, including central and northern New South Wales, southeast Queensland, southeast Melbourne and southwest Western Australia*
- *it has been estimated that 17% of mangroves and 21% of saltmarsh have been lost to coastal development since European settlement with much of this loss focussed in New South Wales and Victoria*
- *only 5% of Australia's coastal estuaries and marine habitats are reserved as Marine Protected Areas*
- *42% of domestic tourism and 50% of international tourism is now marine or coastal based*
- *tropical Australia occupies 42% of the nation's landmass yet generates 65% of its run-off*
- *Queensland's east coast river catchments are estimated to deliver 14 million tonnes of sediments to estuaries and coastal marine waters each year*
- *in NSW, 37% of estuaries have more than half of the land in their catchments cleared of vegetation*
- *around 170 exotic marine species have been introduced to our waters including about 10 serious pests. Pest species include the northern Pacific seastar* Asterias amurensis *(Tas and Vic), the Japanese seaweed* Undaria *(Tas and Vic), the giant fan worm* Sabella *(southern and western Australia) and the European green crab* Carcinus maenas *(southern Australia)*

Different types of coastal waterways

Australia's coastal waterways are diverse. Features such as size, depth, tide patterns, types of basins, freshwater flows, saltiness, temperature and types of sediment all vary among estuaries. As well, there is great variety in plants and animals that live there.

Each estuary is unique but all have been shaped over time by the same set of forces – wave action, the movement of the tides and river flow. These forces determine how the waterway looks and also how it works as part of the coastal environment. As well, they influence the location and type of living places available to plants and animals. This in turn influences the ecology of the estuary.

We classify estuaries into types according to which of the three forces – wave, tide or river has dominated during the evolution of the estuary. Grouping estuaries according to common features is important because it allows us to take lessons of research and management from one place and apply them to other similar estuaries.

In all estuaries, sediment is spread around and reworked by currents from wave, tide and river. The form an estuary takes depends on the relative strengths of these energy sources. This form, in turn, affects water flow, nutrient cycling and ecosystem processes. The figure opposite shows how different coastal waterways can be classified using the relative wave, tide and river energies that shape them.

Over time, wave- and tide-dominated estuaries fill with sediment to become wave- and tide-dominated deltas. As the connection between the river and the ocean increases with time, sediment is pushed out to the sea rather than being stopped.

In all estuaries, sediment is spread around and reworked by currents from river, wave and tide. Striking patterns of sand in the Bega Estuary show these forces of nature at work.

Many factors influence the progress of an estuary towards this mature (delta) stage. These include river flow, estuary size, rock types, the shape of the land, coastal setting and the geography of upstream catchments. Smaller coastal waterways with little river flow form strandplains and coastal lagoons on wave-dominated coasts and tidal creeks or tidal flats on tide-dominated coasts. Embayments (bays) and drowned river valleys are found on coastlines with large bedrock indentations. In some cases bays evolve into estuaries and subsequently deltas as they fill with sediment.

In Australia, there is a clear division between wave- and tide-dominated coasts but it is difficult to get a meaningful measure of river energy. This is because of the highly sporadic and variable nature of river flows.

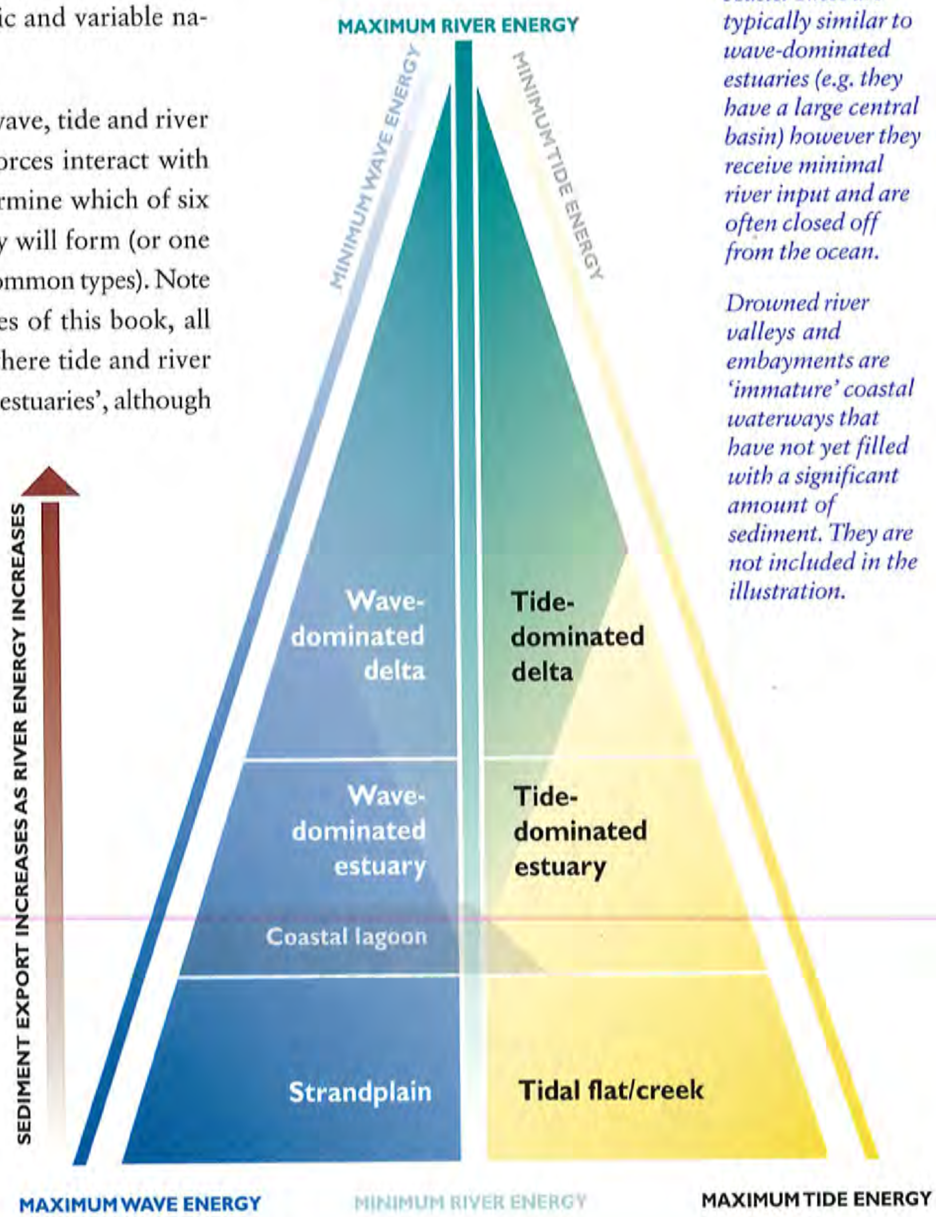
It is the energies of wave, tide and river and the way these forces interact with each other that determine which of six main types of estuary will form (or one of several other less common types). Note that, for the purposes of this book, all coastal waterways where tide and river meet are considered 'estuaries', although geologists use this term for just two of the six main sub-classes.

The patterns of energy translate into different patterns of sediment distribution, which in turn provide different types of habitat for plants and animals. By looking at the form (geomorphology) of the estuary, we can learn something about the wave, tide and river energies which shaped it.

The interaction of three sources of energy – wave, tide and river – determine what type of estuary will form.

Coastal lagoons typically form on wave-dominated – coasts. These are typically similar to wave-dominated estuaries (e.g. they have a large central basin) however they receive minimal river input and are often closed off from the ocean.

Drowned river valleys and embayments are 'immature' coastal waterways that have not yet filled with a significant amount of sediment. They are not included in the illustration.

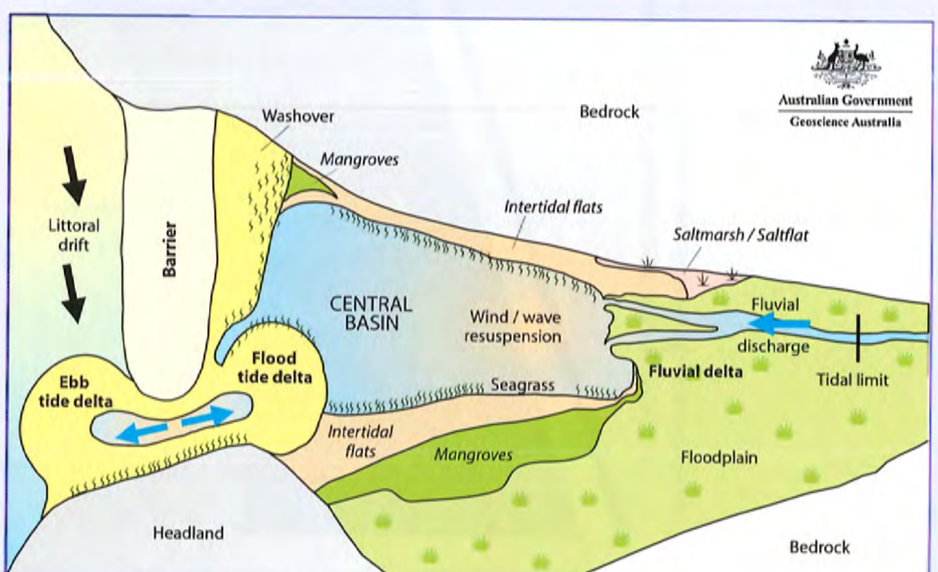


Wave-dominated estuaries

When wave energy is dominant, marine sand can build up to form a barrier across the mouth of a river channel or shallow embayment. Tidal movements create shoals that extend seaward and landward of the inlet. Wave-dominated estuaries typically have a relatively calm central basin or lagoon. Ocean waves cannot penetrate the barrier, and some of the tidal energy is spent crossing the entrance shoals. Coarser sediments from the river flow are deposited at the head of the estuary and fine particles settle out in the central basin. Areas at the edges of the estuary that are inundated by tides form intertidal flats. Here saltmarshes or saltflats, and sometimes mangroves, develop. Swamp forests (e.g. *Melaleuca*) are common in floodplain areas. With its soft sediment and clear water, the lagoon is often a suitable place for seagrasses. Sandy beaches are sometimes present.

Examples include Lake Illawarra (NSW) and Peel Inlet (WA).

Tuross Lake on the far south coast of New South Wales shows the features typical of wave-dominated estuaries.



This conceptual diagram shows the main features of a wave-dominated estuary. Compare it with the photograph of Tuross Lake above.

Coastal lagoons and strandplains

Strandplain creeks and coastal lagoons are small, wave-dominated coastal waterways with very little river input. Coastal lagoons (also known as intermittently closed and open lakes or lagoons, or ICOLLs) are similar to small, wave-dominated estuaries. They are, however, intermittently cut off from the ocean by a sandy barrier. Stream flows are not strong enough for much of the year to keep an entrance open. Under natural conditions, opening only occurs when a large input of catchment run-off breaks the barrier. Coastal lagoons can open seasonally, or sporadically, with heavy rainfall.

Strandplains are sand bodies that run parallel to the shore and contain beach, swale and dune systems. The small interbarrier waterways that drain these systems usually have almost no river input, and are rarely open to the ocean. Strandplains are often associated with extensive wetland and coastal heath systems.

An example of a coastal lagoon is Irwin Inlet (WA); an example of a strandplain is Mooball Creek (NSW).

Oyster Creek in northern NSW shows the typical features of a strandplain creek.

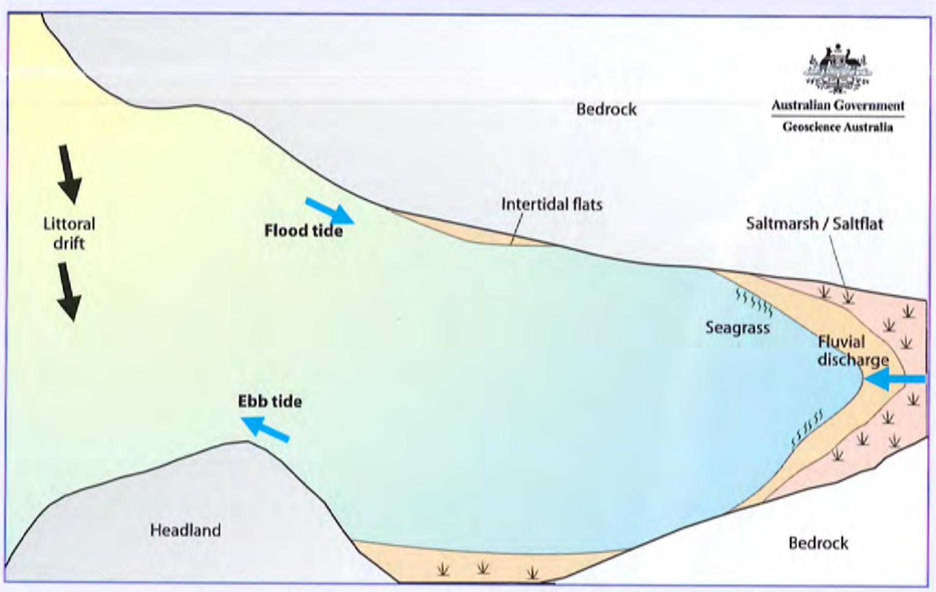
Brou Lake is an intermittently closed and open lagoon. Until there is a flood, river energy will be insufficient to dominate the waves pushing sand against the mouth and keeping the lagoon closed.

Drowned river valleys and embayments

Drowned river valleys and oceanic embayments are easily recognised by their wide mouths flanked by bedrock. Drowned river valleys are deep, steep-sided embayments that were sculpted by river systems when sea levels were much lower than at present. They retain the basic form of the ancient river valley. At the mouth, a submerged tidal delta of marine sediments may represent the partial formation of a sand barrier on wave-dominated coastlines. Embayments and drowned river valleys also occur on tide-dominated coasts, for example, the Kimberley. The head of the estuary is often beginning to fill with sediment from the catchment, leading to the formation of floodplains with tidally influenced river channels. Oceanic embayments are partially enclosed, bedrock-dominated coastal features that may have formed in a number of ways, depending on the underlying geological structure. On wave-dominated coastlines, submerged barriers have not formed across the embayments because of depth and lack of sediment.

An example of a drowned river valley is the Derwent River (Tas); Jervis Bay (NSW) is a typical embayment.

The Derwent Estuary is a drowned river valley.



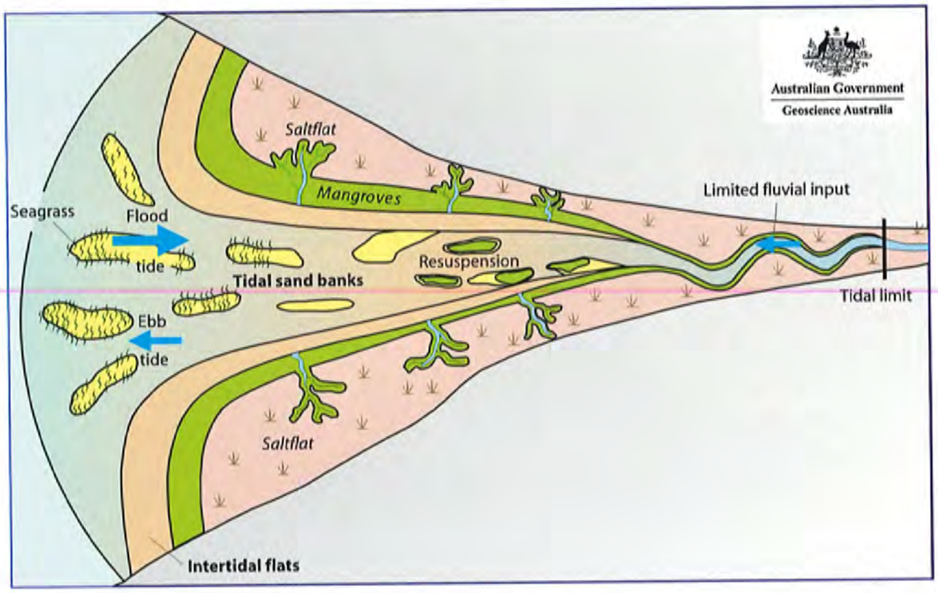
This conceptual diagram illustrates the processes that shape an embayment.

Tide-dominated estuaries

Tide-dominated estuaries are funnel-shaped estuaries with strong tidal currents and often high tidal ranges. Intertidal flats, mangroves and saltflats/saltmarshes are a feature along the margins and behind the estuary channel. Sediment is both deposited and eroded in these flanking areas, but a general trend of slow growth in intertidal habitats occurs. This is because plants such as mangroves and saltmarshes trap sediment and help it stick together. Tidal currents build long tidal sandbanks along the length of the estuary. As the flood tide moves up the funnel-shaped channel it is constricted. This can lead to an increase in tidal range (also known as tidal amplification) within the estuary. Tide-dominated estuaries accumulate sediment from upstream catchments and from the sea, but much of this sediment load can be flushed offshore during floods. Tidal movement continually stirs up fine sediment particles in the estuary. As a result the water of these estuaries is naturally turbid. Tide-dominated estuaries are common across northern Australia.

Examples include the Ord River (WA) and Broad Sound (Qld).

The Fitzroy, a tide-dominated estuary in central Queensland



Conceptual diagram of a tide-dominated estuary

Tidal creeks and tidal flats

Tidal flats are wide, gently sloping accumulations of fine sediment that form muddy plains dissected by numerous tidal channels. They are common in northern Australia where tidal ranges tend to be high. Typically they have very little catchment input (except during wet season flows). The most extensive tidal flats are in areas with very high tidal ranges such as northwest Western Australia, and along flat muddy coasts such as the Gulf of Carpentaria.

This muddy tidal flat in King Sound, Western Australia is drained by many small meandering channels.

Tidal creeks are small tidal channels cut into tidal flats, draining and filling the flats during each tidal cycle. In tidal creek systems, seawater flow is restricted to the tidal channel.

An example of a typical tidal flat system is Moonlight Creek (Qld) located on the south coast of the Gulf of Carpentaria, and Good-enough Bay (WA).

This creek on the western shore of Fraser Island is a typical tidal creek with one clearly visible channel (below).

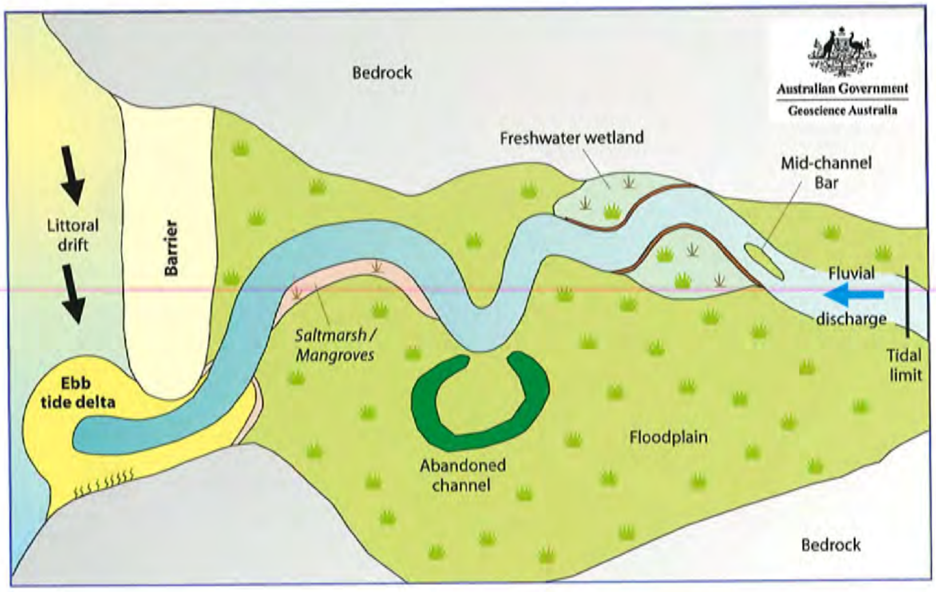
Wave-dominated deltas

When the central basin of a wave-dominated estuary fills with sediment, the river is left as a meandering, shifting channel in a low-lying floodplain. Wave-dominated deltas have often been created by vast river systems with high sediment loads. River energy is dominant throughout the estuary because a central basin no longer reduces it. As a result there is a net movement of sediment out into the ocean.

At the entrance, high wave energy is reduced by bars across the river mouth. Shoaling results from tidal movement through the narrow entrance. Levees, back swamps and abandoned river channels are found on the floodplain, which accumulates sediment during floods. Limited areas of intertidal flats and saltmarsh or saltflats may be present.

Examples include the Manning River (NSW) and Yarra River (Vic).

The Manning River (NSW) shows the evolution of a wave-dominated delta. Sediment has filled a central basin forming islands and a shifting river channel.



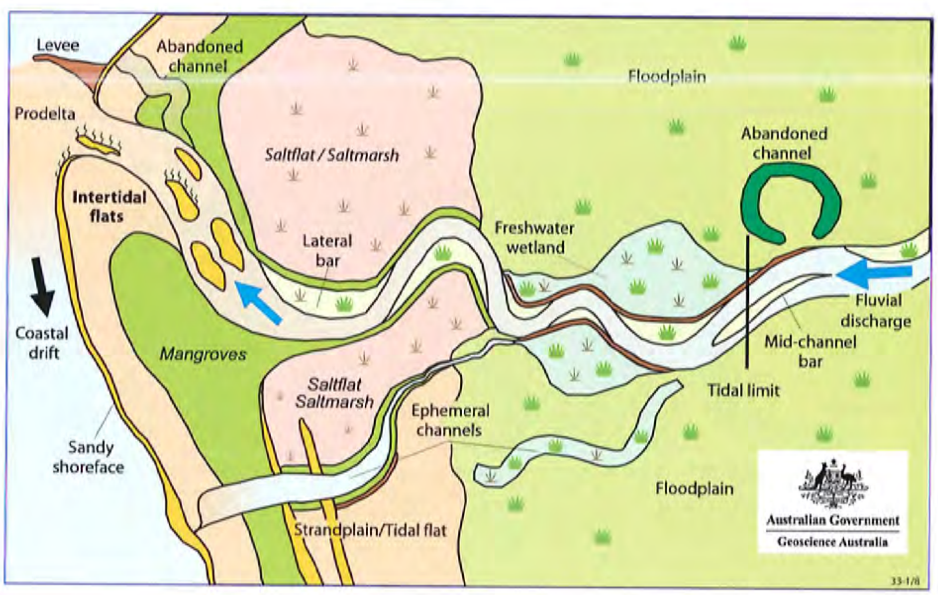
In this conceptual diagram of a wave-dominated delta, note that the central basin of the estuary diagram (see page 8) has been filled in and replaced by a stream meandering through sediment deposits.

Tide-dominated deltas

In tide-dominated deltas, most of the sediment is carried into the ocean. Sediment may also be trapped by the vast areas of intertidal flats, mangroves and saltflats/saltmarshes along the flanks of the river channels. These processes result in a slow seaward migration of all estuary habitats and sedimentary environments. Viewed from above, a tide-dominated delta often forms a distinct lobe-shaped bulge from the coast. Tidal sandbanks develop parallel to the direction of tidal movement with the accumulation of coarse sediment moved from offshore and catchment sources. These sandbanks extend further offshore compared to those in tide-dominated estuaries. Tide-dominated deltas often have many branching, ephemeral and abandoned channels, back swamps, and long, narrow islands. The presence of strong tidal currents means that these systems are naturally turbid.

Examples include the Macarthur River (NT) and Burdekin River (Qld).

The mouth of the Burrum River in Queensland shows the features of tide-dominated deltas, including tidal sandbanks visible in the upper right of the photograph.



Conceptual diagram of a tide-dominated delta; the photograph of Burrum Heads above shows many features of the diagram.

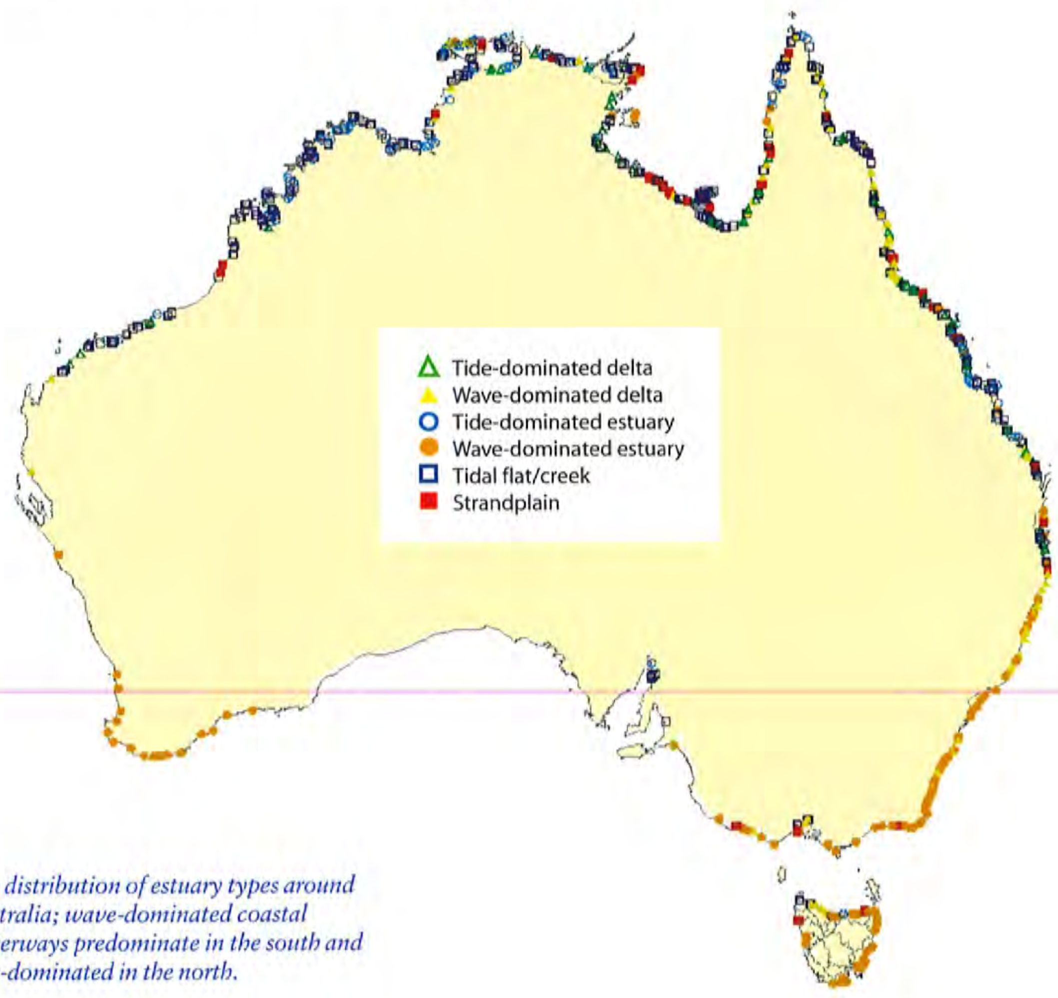
Distribution of estuary types around Australia

The six major subclasses of Australian estuaries and coastal waterways are based on how wave, tide and river energies interact to shape them. The overall form (geomorphology) of the estuary can be used as a further basis for classification. The classification by form confirms the energy classification.

Less than a third (28%) of Australian coastal waterways are actually 'estuaries' from a geological view point. The rest are deltas (tide- or wave-dominated) (19%), strandplains (5%) or tidal creeks (35%).

A seventh subclass 'others' (13%) includes drowned river valleys, embayments and coastal lakes/lagoons/creeks. Strandplains and tidal creeks form in places with very low river energy. Jointly, they account for about 40% of Australia's coastal waterways. This reflects the fact that Australia is a dry continent, with relatively little river run-off by world standards.

The map below shows the diversity and distribution of the various estuary types around Australia.



The distribution of estuary types around Australia; wave-dominated coastal waterways predominate in the south and tide-dominated in the north.

Tides, waves and rivers – energies that shape estuaries

As the previous map shows, wave-dominated waterways predominate in the south of the continent while tides are dominant in shaping northern estuaries. This reflects the greater exposure of the southern coast to wave action, whereas in the north, the average annual wave energy is low but tidal variation is great. Rainfall, which determines the contribution of river energy to shaping estuaries, also varies between regions. Each of these energies – wave, tide and river, and how their regional variations affect the shaping of estuaries – are explored here.

Waves

Ocean waves are predominantly generated by winds on the water's surface. Some may have sufficient energy to be transmitted across entire oceans. As waves approach the coast, the ocean depth lessens causing the waves to slow and bunch together, thereby increasing their height. The greater the distance over which this occurs, the higher the wave becomes. Waves tend to break when the water depth is slightly less than their height.

Because waves rarely approach parallel to the coastline, sand and debris are carried obliquely up the beach. Water then runs back by the shortest path. Thus, successive waves carry sand along the beach in a zig-zag fashion. Over time, millions of tonnes of sand can shift along a beach. This 'longshore drift' causes the bars that build up at the mouths of wave-dominated estuaries.

Relative wave heights around the coast of Australia; in the south, waves travel long distances to reach our shore and consequently build to great heights.

Tides

The ebb and flow of tidal patterns familiar to any one Australian are unlikely to relate to more than a small section of the shoreline. Australia has a diversity of tide frequencies including two daily tides, one or two daily tides or one tide (see figure). Tides originate from the gravitational pull of the Sun and Moon but the diverse tidal pattern we experience is complicated by the shape of the ocean floor and coastlines. The timing and height of tides is also influenced by the Earth's rotation.

As an incoming tide moves across the continental shelf surrounding a land mass, it slows and steepens, forming a wave, a process known as shoaling. The larger the shelf, the steeper the tidal 'wave'.

A broad continental shelf results in a quickly rising but slowly ebbing tide and increases the difference in height between the high and low tides.

The difference between high and low tides varies dramatically across Australia. In north western Australia the range may be up to 12 metres, while south of Perth, tidal variation may be imperceptible.

Variations in the coastline also affect tides. Where a bay has a wide entrance but narrows inshore, the rising tide is confined and therefore magnified. However, a wide bay with a narrow entrance such as Port Phillip Bay in Victoria, has a smaller range because the water flowing in is restricted at the entrance then spreads over a wide area in the bay.

wide tidal range
medium tidal range
narrow tidal range

Tidal range on Australia's coast

two tides a day
two different tides a day
one or two tides a day
one tide a day

Number of tides per day

From Guide to the Australian Coast, Reader's Digest 1983

Rivers

Australia is the world's driest inhabited continent, so the amount of water flowing to the sea from our rivers is small by world standards. In southern regions, climates, whether wet or dry, are fairly constant year round. The north is influenced by monsoons. River flow is highly seasonal and in the wetter years major floods affect estuaries with large catchments.

Catchment topography also affects river flow with steep coastal catchments producing more energetic rivers.

very dry, except monsoonal cyclones
rain in winter only
dry throughout the year
moist throughout the year
wettest in summer
monsoonal, warm wet summers
monsoonal, hot wet summers

From LOICZ reports and Studies No 12, 1999

Differing climate patterns around the Australian coast cause river energy to vary both geographically and seasonally.

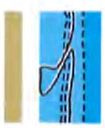
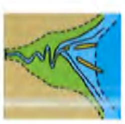
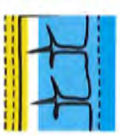
Management implications of the process-based classification

Classification is a valuable management tool because the different types of estuaries identified in this chapter respond in different ways to change generated by humans. If we know what sort of estuary we are dealing with we can deduce something about how the estuary can be expected to respond under pressure from human population.

Generally there is a strong relationship between the size of a catchment's population and the degree to which its estuary has been modified away from the original pristine condition. However, the link between population and estuary condition is not a simple one.

Tide-dominated waterways tend to have large entrances and no major constricting channel. They are relatively long and narrow compared with entrance width, and do not feature large central basins. These features imply a tendency for water (and

Characteristics of different kinds of estuaries, with implications for management

dominant energy	Type of Coastal Environment	Sediment Trapping Efficiency	Turbidity	Circulation	Habitat change due to sediment
wave	 Wave-dominated estuary	High	Naturally low	Salt wedge/ partially mixed	High risk
wave	 Strandplain	Low	Naturally low	Negative/ Salt wedge/ partially mixed	Low risk
tide	 Tide-dominated estuary	Moderate	Naturally high	Well mixed	Some risk
tide	 Tidal flats	Low	Naturally high	Well mixed	Low risk
river	 Wave-dominated delta	Low	Naturally low	Salt wedge/ partially mixed	Low risk
river	 Tide-dominated delta	Low	Naturally high	Well mixed	Low risk

whatever it is carrying such as sediment and nutrients) to flow directly along the length of the estuary and out to sea. By contrast, wave-dominated waterways tend to have narrow constricted entrances and large widths compared with the entrance opening. The energy of the river slows when it reaches the central basin. The barrier typically formed by wave movement tends to prevent flushing of the estuary. Sediment, nutrients and pollution can be trapped in the estuary until washed out by a flood in the river catchment.

Tide-dominated systems, on the other hand, do trap sediments and pollution in their extensive intertidal mangrove/saltmarsh areas but generally with less of a detrimental affect on the condition of the estuary.

Tide-dominated subclasses have much longer perimeters than wave-dominated systems. They have far larger and more complex shorelines with more potential living space for mangroves and saltmarshes in their intricate drainage networks.

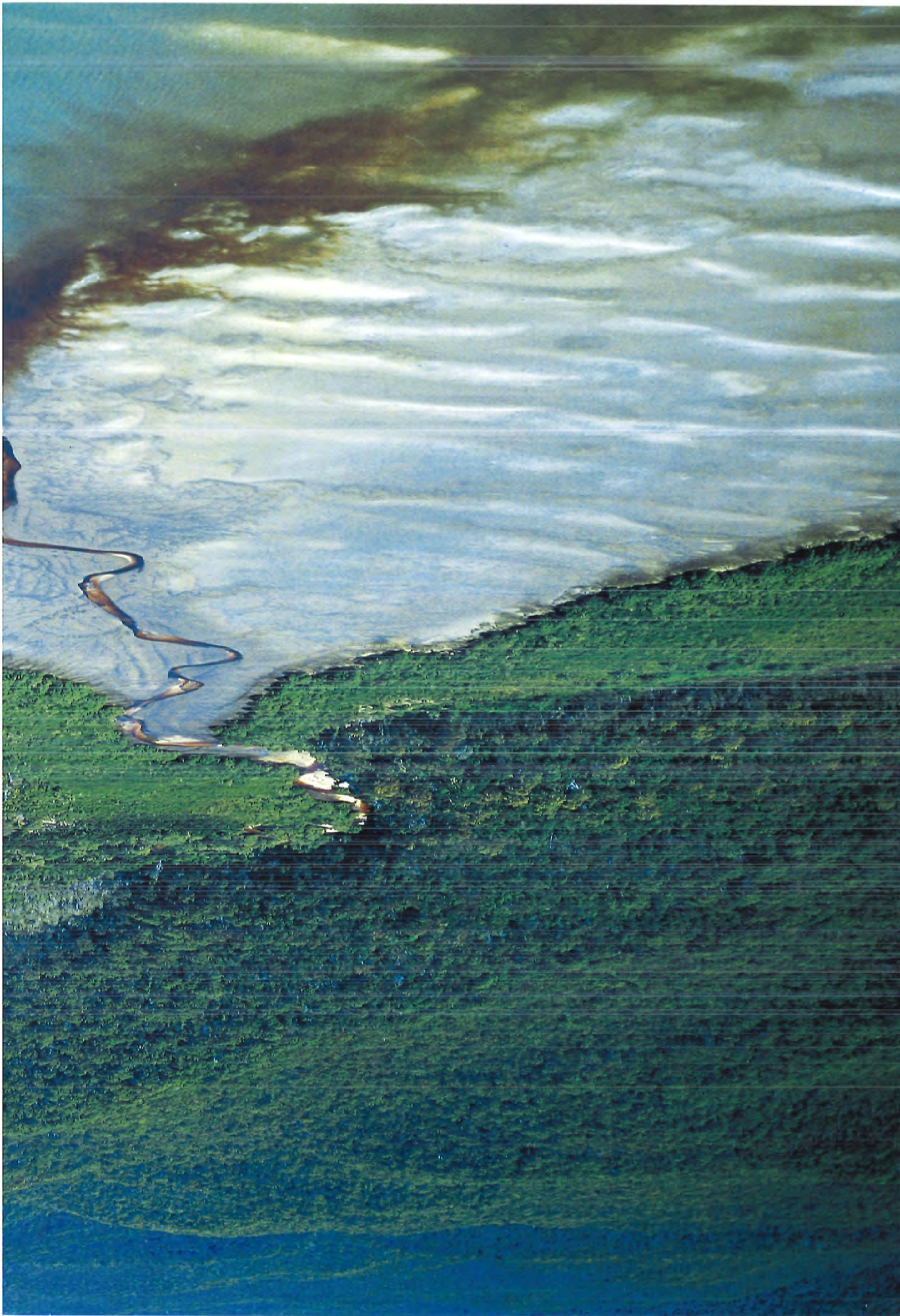
Environmental features also differ between these two basic types of coastal waterways. For example, saltflats and saltmarshes, mangroves, tidal sandbanks and intertidal flats are typical of tide-dominated waterways. Tide-dominated systems also tend to form more extensive deltas where the estuary meets the sea. By comparison, central basins, barriers and back-barriers are associated with wave-dominated subclasses and in these wave-dominated systems, deltas form where the river flows into the estuary. Looking at the six subclasses described earlier, the following features are dominant in each subclass:

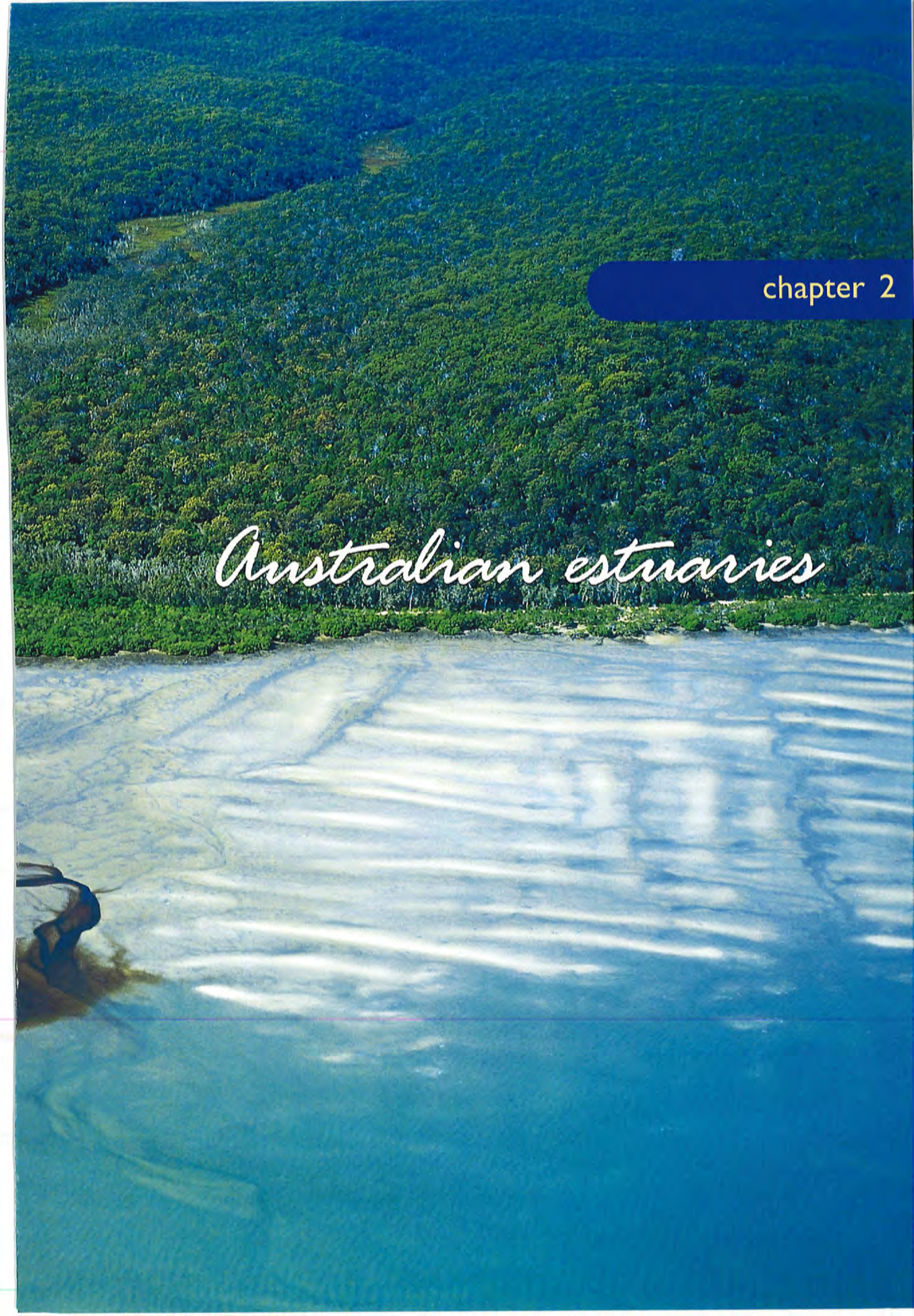
- the central basin is dominant in wave-dominated estuaries;
- mangroves and channels are dominant in wave-dominated deltas;
- intertidal flats, barrier/back barriers and channels are dominant in strandplains;
- mangroves, saltmarsh and channels are dominant in tide-dominated estuaries;
- mangroves are dominant in tide-dominated deltas; and
- mangroves and saltmarsh are dominant in tidal creeks.

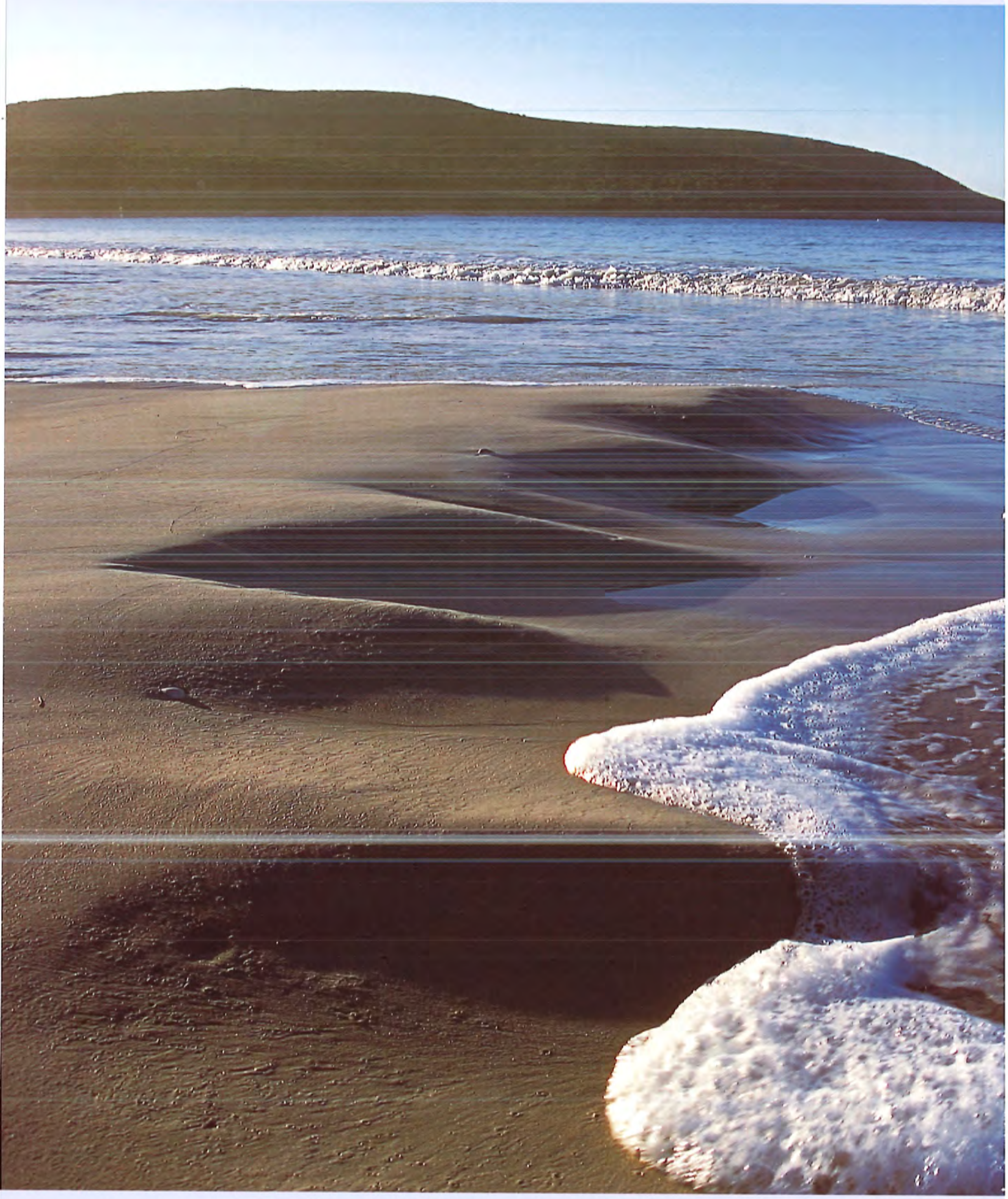
Over time, estuaries change shape as sediment is moved about by natural processes. These changes are usually slow from a human view point, occurring over years or decades, but they are fairly rapid in geological time scales.

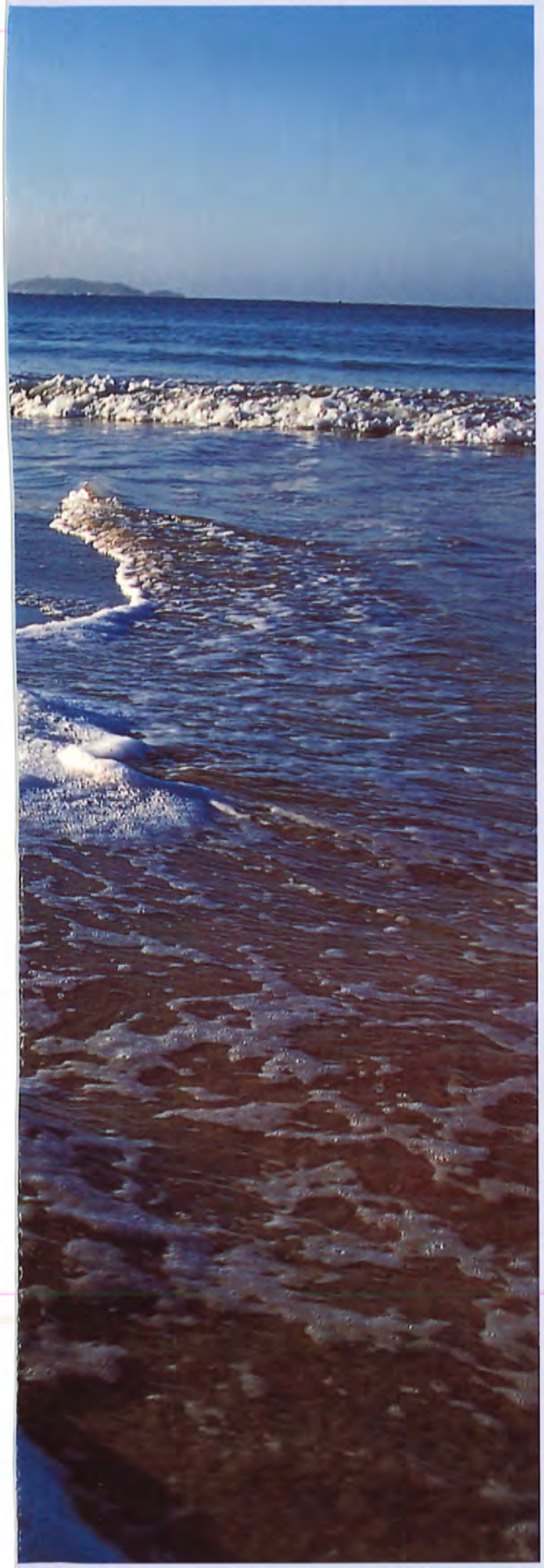
To manage estuaries well, we must consider their ever-changing nature and the impact of our actions on them. Some types of estuaries are naturally more easily damaged by increased loads of sediment and by toxic substances which get into coastal waterways. This is because of their structure and how they work. For example, wave-dominated estuaries trap sediment, so are more vulnerable to habitat loss due to sedimentation.

The table on the previous page illustrates characteristics of different types of estuaries. These characteristics have implications for how the estuaries are managed.




chapter 2
Australian estuaries

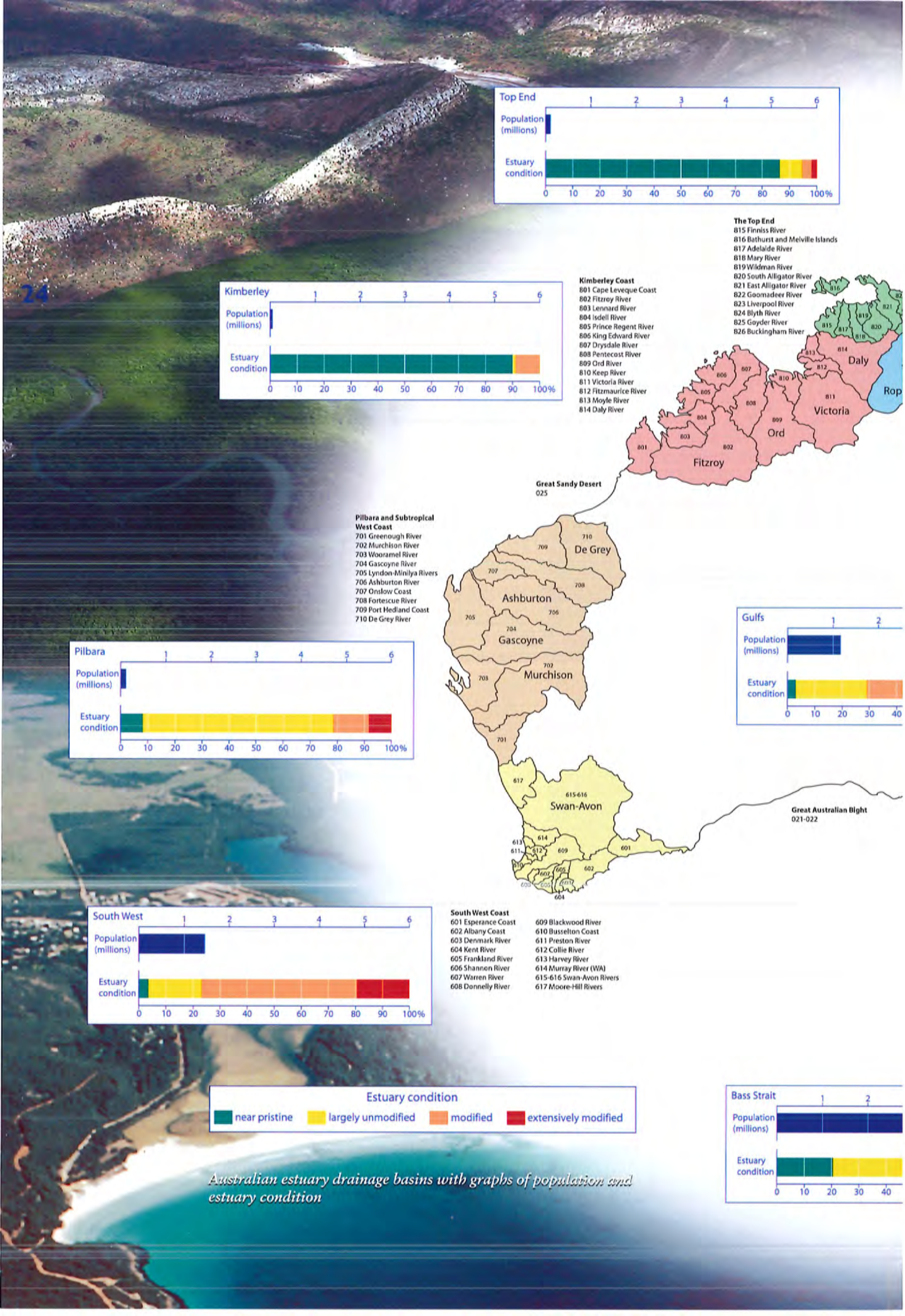




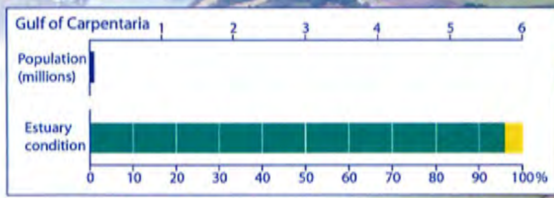
In this chapter, we tour the Australian coast, travelling clockwise from northern New South Wales. We look at the features of the estuaries in each region. Within regions, coastal waterways tend to have many similarities. This is because common factors form and shape them. For example, the southern half of our continent is exposed to strong ocean currents and is wave-dominated. The north, on the other hand, tends to be more protected by landmasses in the region, including other parts of our own coastline. These landmasses reduce the intensity of wave action but they also constrict and funnel tide movements, amplifying their effects on the coast. The results of this can be extreme and surprising. For example, in the Gulf of Carpentaria many estuaries experience just one tide cycle per day.

Patterns of human settlement also have regional effects on estuaries, as the illustration on the following page shows. The first permanent European settlements were on the wave-dominated coasts of New South Wales and Victoria. Wave-dominated estuaries are more likely to be affected by pollution because they are less well flushed. These factors combine to make water quality an issue in the more populated parts of southeastern Australia. At the other extreme, in every sense, is the Kimberley region in the northwest. Here, the population is sparse and half the people living in the region are Aboriginal. The Kimberley has Australia's most extreme tides – up to 12 m. Estuaries are well flushed and most of them are in near-pristine condition.

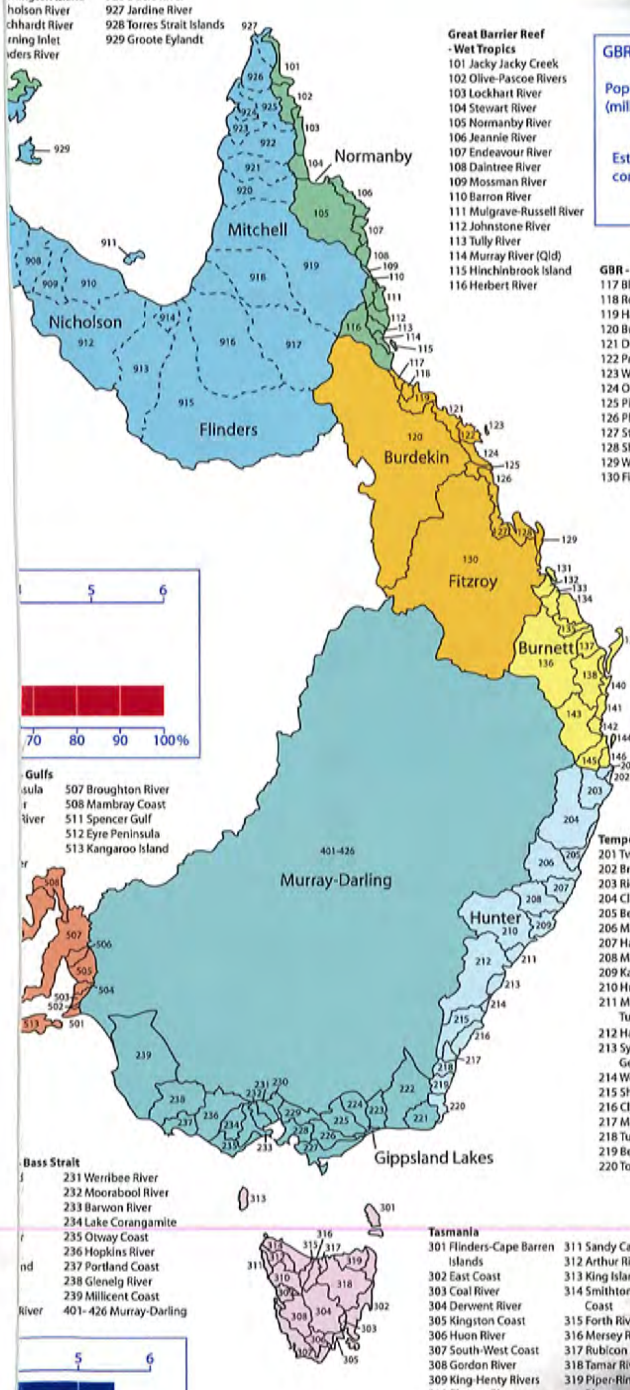
King George Sound, Albany, WA



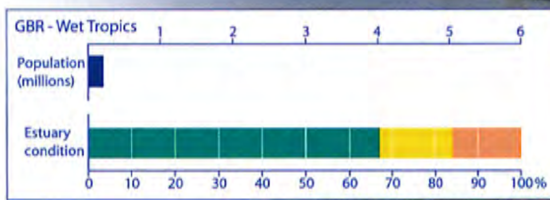
Australian estuary drainage basins with graphs of population and estuary condition



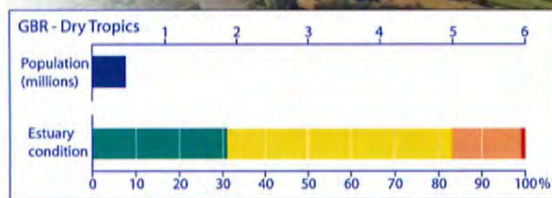
Carpentaria
ılatong River
ker River
ɔer River
ms River
ımen Bight River
ıle River
Arthur River
ɔinson River
vert River
tlement Creek
rnington Island
holson River
chhardt River
rning Inlet
ıders River
916 Norman River
917 Gilbert River
918 Staaten River
919 Mitchell River
920 Coleman River
921 Holroyd River
922 Archer River
923 Watson River
924 Embley River
925 Wenlock River
926 Ducie River
927 Jardine River
928 Torres Strait Islands
929 Groote Eylandt



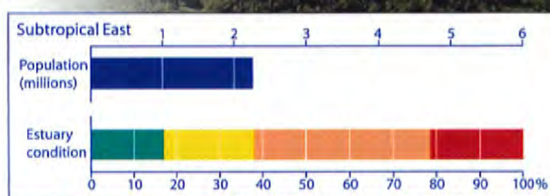
Great Barrier Reef - Wet Tropics
101 Jacky Jacky Creek
102 Olive-Pascoe Rivers
103 Lockhart River
104 Stewart River
105 Normanby River
106 Jeannie River
107 Endeavour River
108 Daintree River
109 Mossman River
110 Barron River
111 Mulgrave-Russell River
112 Johnstone River
113 Tully River
114 Murray River (Qld)
115 Hinchinbrook Island
116 Herbert River



GBR - DryTropics
117 Black River
118 Ross River
119 Haughton River
120 Burdekin River
121 Don River
122 Proserpine River
123 Whitsunday Island
124 O'Connell River
125 Pioneer River
126 Plane Creek
127 Styx River
128 Shoalwater Creek
129 Water Park Creek
130 Fitzroy River

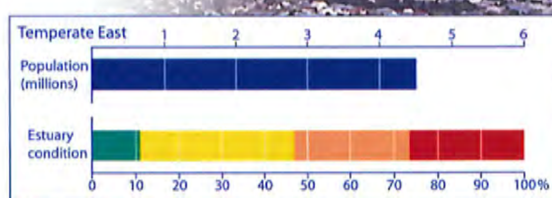


Subtropical East Coast
131 Curtis Island
132 Calliope River
133 Boyne River
134 Baffle Creek
135 Kolan River
136 Burnett River
137 Burrum River
138 Mary River (Qld)
139 Fraser Island
140 Noosa River
141 Maroochy River
142 Pine River
143 Brisbane River
144 Stradbroke Island
145 Logan-Albert Rivers
146 South Coast



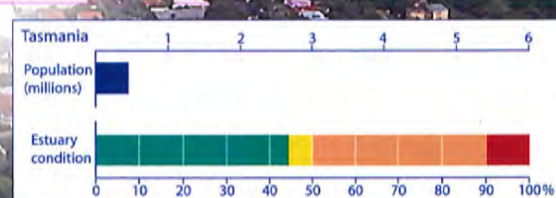
Gulfs
ısula 507 Broughton River
r 508 Mambray Coast
River 511 Spencer Gulf
512 Eyre Peninsula
513 Kangaroo Island

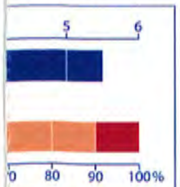
Temperate East Coast
201 Tweed River
202 Brunswick River
203 Richmond River
204 Clarence River
205 Bellinger River
206 Macleay River
207 Hastings River
208 Manning River
209 Karuah River
210 Hunter River
211 Macquarie and Tuggerah Lakes
212 Hawkesbury River
213 Sydney Coast-Georges River
214 Wollongong Coast
215 Shoalhaven River
216 Clyde River-Jervis Bay
217 Moruya River
218 Tuross River
219 Bega River
220 Towamba River



Bass Strait
231 Werribee River
232 Moorabool River
233 Barwon River
234 Lake Corangamite
235 Otway Coast
236 Hopkins River
nd 237 Portland Coast
238 Glenelg River
239 Millicent Coast
River 401-426 Murray-Darling

Tasmania
301 Flinders-Cape Barren Islands
302 East Coast
303 Coal River
304 Derwent River
305 Kingston Coast
306 Huon River
307 South-West Coast
308 Gordon River
309 King-Henty Rivers
310 Pieman River
311 Sandy Cape Coast
312 Arthur River
313 King Island
314 Smithton-Burnie Coast
315 Forth River
316 Mersey River
317 Rubicon River
318 Tamar River
319 Piper-Ringarooma Rivers





Temperate East Coast

The temperate east coast, from the Tweed River at the Queensland–New South Wales border to East Gippsland, Victoria, is a wave-dominated coast. Typical estuaries have entrance bars and heavy shoaling. The large drowned river valleys in the Sydney region are the exception to this. Some 60 percent of New South Wales estuaries are intermittently closed or open lakes and lagoons (ICOLLs). Their ecosystems are sensitive to nutrient enrichment (a form of pollution) from cities and farms.

Manning River on the temperate east coast of New South Wales

Approximately 80 percent of people in New South Wales live near an estuary. Estuaries are important for tourism. They also face increasing pressures from urbanisation and development. There are extensive areas of wetland for land- and water-dwelling animals, though much has been lost to urbanisation. In recent years, there has been a pattern of landward movement of mangroves into saltmarsh areas in temperate eastern Australia. Up to 80 percent of saltmarsh has been lost in some places. Many of the estuaries here support commercial fish, prawn and oyster production. Declining water quality has led to shellfish closures in some estuaries.

This region has several national parks that protect estuaries and their catchments. Surfing and recreational fishing are popular. Many estuaries have been permanently opened, and dredging for navigation is common.

Key Features

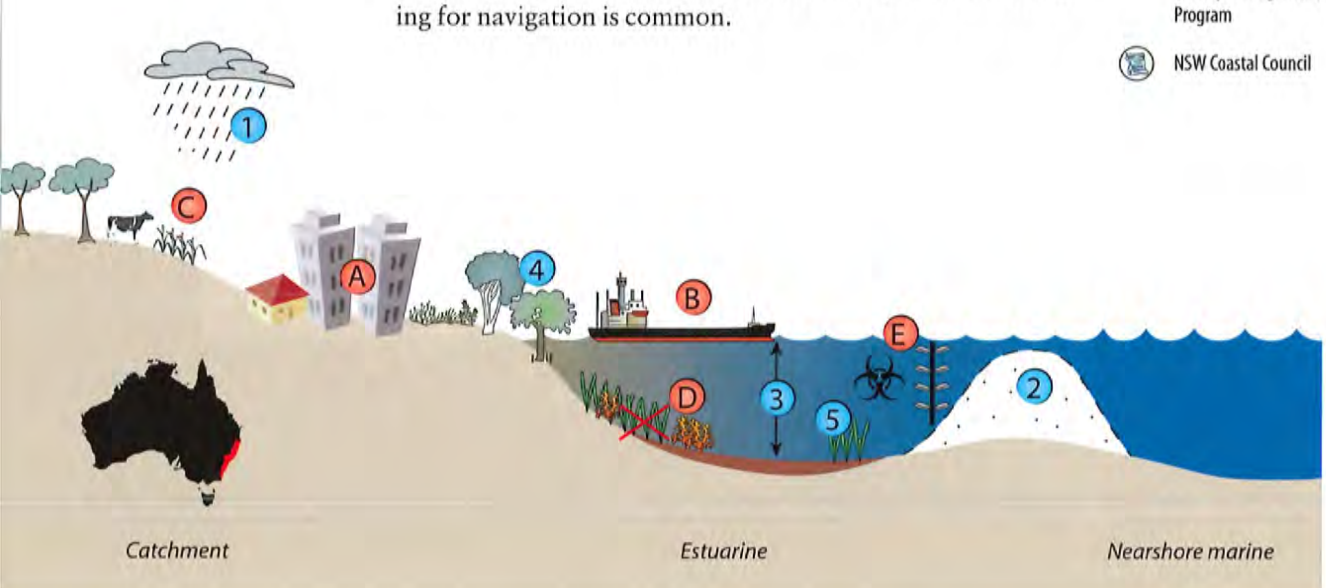
1. Uniform average annual rainfall
2. Wave-dominated systems: many have bars/shoaled entrances
3. Variable depth
4. Mangroves (low diversity) and saltmarsh (high diversity)
5. Temperate seagrass - slow recovery

Major Threats

A. Heavily populated/ urbanised
B. Intense use: development, shipping, fishing
C. Agriculture (diverse)
D. Eutrophication
E. Pathogens

Management Arrangements

- NSW State Government: DLWC Estuary Management Program
- NSW Coastal Council



Southern Ocean – Bass Strait

This region extends from Mallacoota Inlet in eastern Victoria to The Coorong and Lower Lakes in South Australia. Winter rainfall occurs across the region. Summer rainfall generally decreases from east to west. Coastal lagoons and wave-dominated estuaries are typical of the region, apart from the large embayments of central Victoria. Much of the coastline is rugged and rocky. Large areas of seagrass, mangrove and saltmarsh are found in Western Port and Port Phillip Bay. Vast wetland areas are also associated with the Gippsland Lakes and Coorong estuaries. In general, the small coastal lagoons of western Victoria support a less diverse flora and fauna than the larger estuaries in the east. Many estuaries throughout the region have been modified by urbanisation, industry, agriculture and forestry in catchments. Water has also been diverted and extracted, further modifying estuaries.

Many of the estuaries in eastern Victoria are in national parks and are valuable conservation and wilderness areas. The large embayments of Western Port and Port Phillip Bay in central Victoria are major ports and include the most heavily urbanised areas in the region. Many of the small estuaries in western Victoria have only ephemeral openings. They collect nutrients, sediments and toxicants from steep agricultural catchments.

This rugged, rocky coastline is typical of much of the Bass Strait region.

Key Features

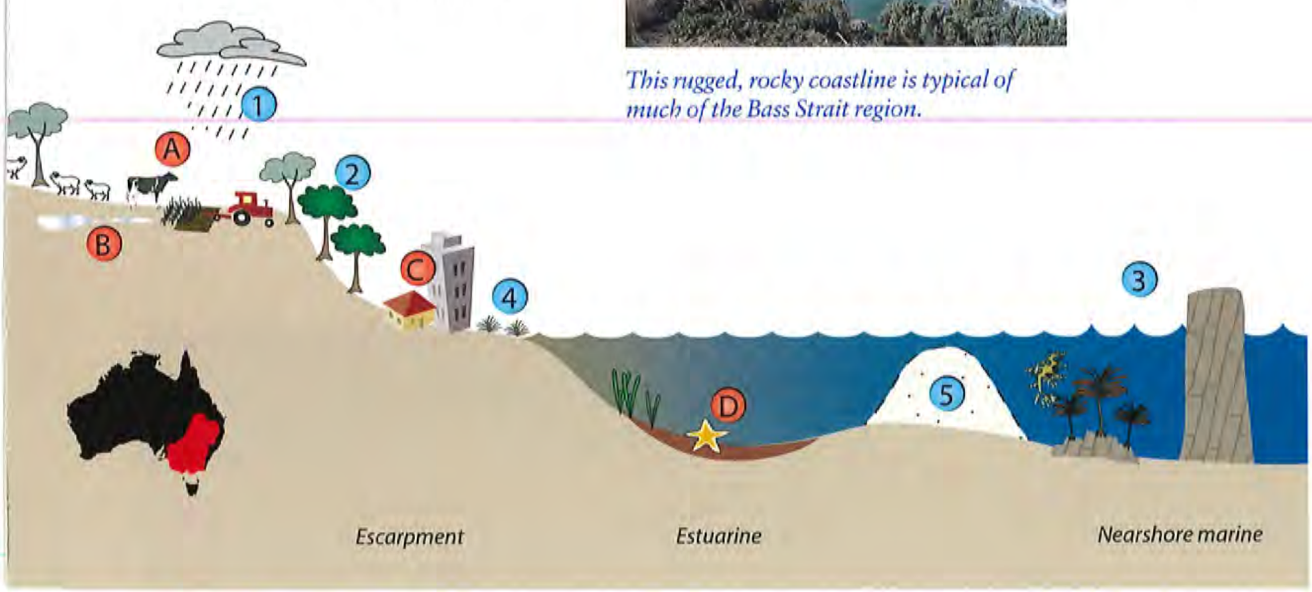
1. Mostly winter rainfall
2. Small, relatively steep catchments
3. Rugged coastline with temperate rocky reefs
4. Saltmarshes
5. Constricted, wave-built estuary entrances

Major Threats

A. Grazing (sheep, cattle) and horticulture
B. Salinity
C. Population centres
D. Introduced species

Management Arrangements

- International obligations: Ramsar
- Regional marine planning process nearing completion
- Victorian Coastal Council



Tasmania

Tasmanian estuaries vary greatly in form. Among the reasons for this are: extreme differences in wave energy and rainfall between the west and east coasts, a greater tidal range on the north coast, and differences in coastal landforms. Catchments are typically short and steep. Some of the most pristine estuaries in Australia are found in the rugged and remote southwest of Tasmania, protected in the World Heritage Area. These estuaries are important for recreation and for their place in Australian culture.

Bicheno, on Tasmania's east coast

Of Tasmania's non-pristine estuaries, many are degraded by agriculture, forestry and urban development. The main cities of Hobart and Launceston are on the shores of the Derwent and Tamar estuaries respectively. Both estuaries have felt the severe impact of urban, industrial and agricultural development. Yet they have high levels of biodiversity and many species found here are unique to this part of Australia.

For estuaries with hydroelectric dams and upstream irrigation, an important issue is making sure enough water flows to keep the environment healthy. Mining has had a major impact on some estuaries. The presence of introduced marine pests such as toxic dinoflagellates and New Zealand screw shells threaten the ecology of many Tasmanian estuaries. A number of estuaries contain marine farming areas important to the local economy. Balancing estuary use with conservation is an issue.

Key Features

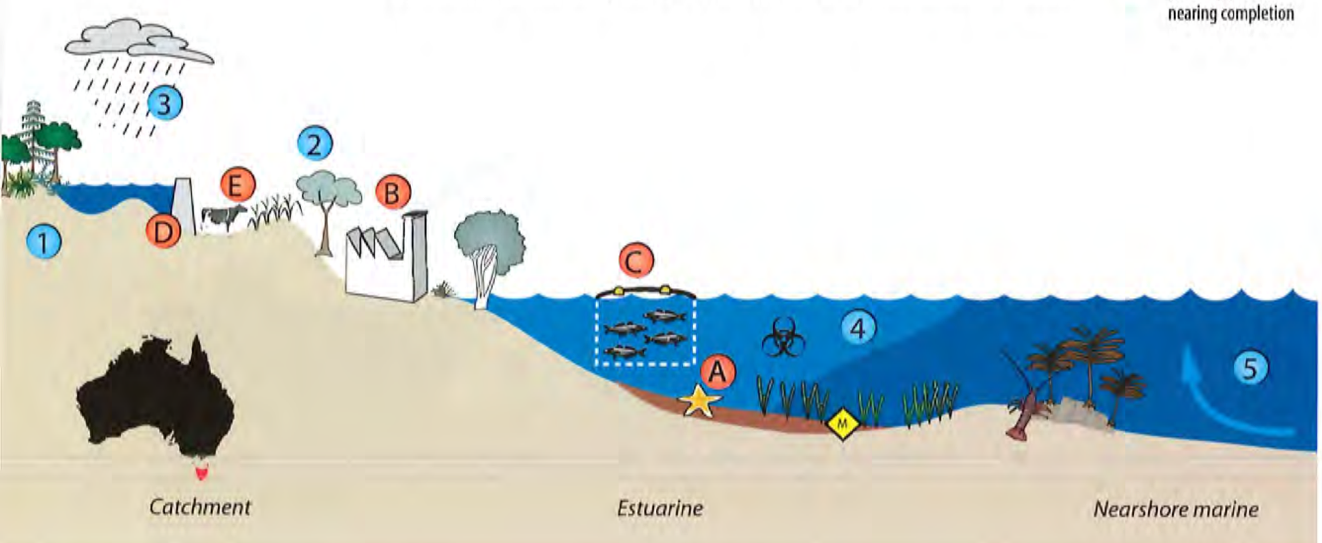
1. Diverse systems: rainfall, impacts, catchments, wave/tide-dominated
2. Small, hilly catchments
3. Uniform, winter rainfall
4. Salt wedge/ stratification
5. Ocean upwellings

Major Threats

A. Introduced species
B. Industrial and mining impacts: e.g. metals, pulp mill effluent
C. Aquaculture
D. Impoundments (hydroelectricity)
E. Agriculture and grazing

Management Arrangements

- International obligations: World Heritage
- Coordinated State government approach: DPIWE
- Regional marine planning process nearing completion



Southern Ocean – Gulfs

Port Germain jetty at the landward end of Spencer Gulf shows typical features of a tide-dominated coast.

This region consists of two large gulfs, Gulf St Vincent to the east, Spencer Gulf to the west. The climate is generally semi-arid, but winter rainfall comes in relatively reliable showers that support large areas of dryland agriculture (wheat). Rainfall decreases from south to north. The gulfs are large, inverse estuaries, that is, salinity increases away from the ocean due to evaporation. These estuaries are unusual in other ways. For example, they are dominated by wave energy in the southern reaches but tidal energy predominates at the landward ends of the gulfs, where extensive tidal flats have formed.

These support vast areas of samphire, saltmarsh, and single-species mangrove stands. Massive seagrass beds in the shallow waters of the gulfs are vital to South Australia's commercial and recreational fisheries. These catchments are some of the most extensively cleared in Australia, with land use dominated by grazing and wheat growing. The sandy, semi-arid catchments are vulnerable to degradation and soil loss by wind and water erosion. Estuaries have also been affected by industrial and urban land uses along eastern Gulf St Vincent and in upper Spencer Gulf. Urban, industrial, port and shipping impacts are a major concern in Adelaide's Port River–Barker Inlet estuary system.

Key Features

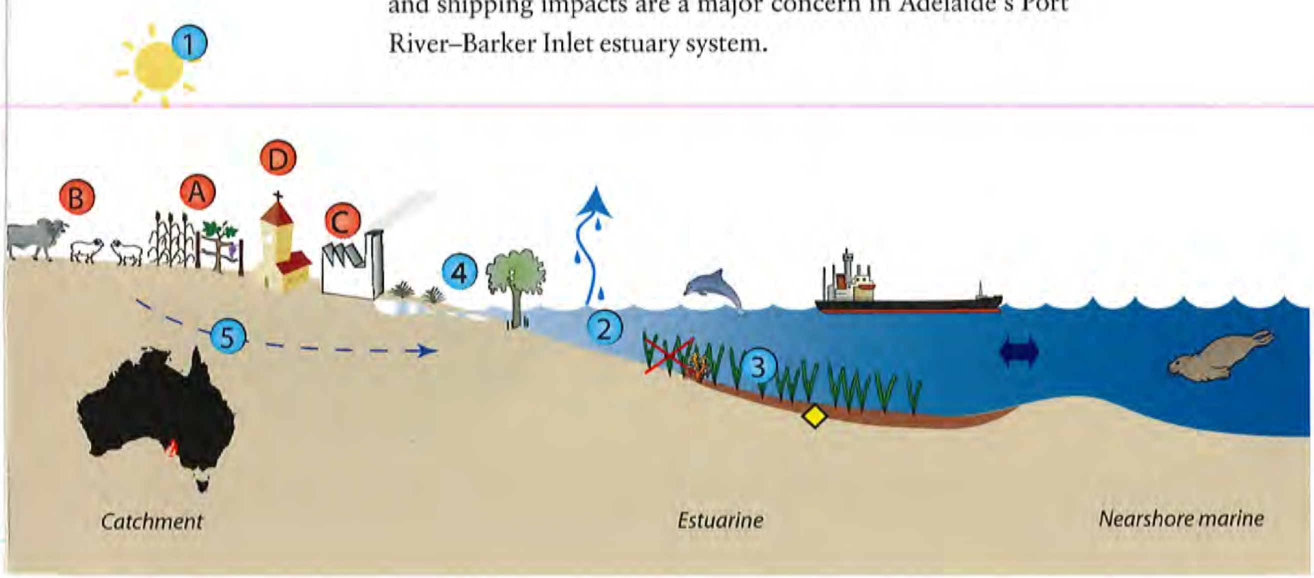
1. Arid, cleared catchments; winter rainfall
2. Hypersaline (inverse estuaries)
3. Vast seagrass meadows
4. Mangroves and saltmarsh
5. Groundwater

Major Threats

A. Agriculture (wheat, vines)
B. Grazing (sheep and cattle)
C. Industry and port development
D. Population centres

Management Arrangements

- International obligations: Ramsar
- Coasts and oceans reporting



South West Coast

This region includes the southwest corner of Western Australia, north to the Hill River and east to Barker Inlet near Esperance. The far southwest corner is the wettest part of Western Australia. The predominantly winter rainfall drops away to the north, the east and inland. Estuaries here are wave-dominated. Along the south coast, many small coastal lagoons open to the ocean seasonally or sporadically, while most estuaries north from Cape Leeuwin are seasonally or permanently open.

Melaleuca fringed coast at Pink Lake, Esperance

Several estuaries have seagrass, mainly *Ruppia megacarpa*. This is eaten and distributed by waterbirds such as black swans. Saltmarsh and melaleuca swamps are common in these estuaries, but mangroves are absent, except in the Leschenault estuary at Bunbury. South west estuaries have mostly been heavily impacted by human activities. These include catchment clearing, draining and channelling of wetlands, dryland agriculture, horticulture, dairy, beef and piggery operations, and urbanisation. The sandy catchment soils have poor nutrient-holding capacity. As a result, a lot of nutrients end up in estuaries via rivers and groundwater. This has led to numerous problems including nuisance and toxic algal blooms, seagrass loss and fish kills. Salinity is increasingly a problem in cleared, low-rainfall catchments.

Key Features

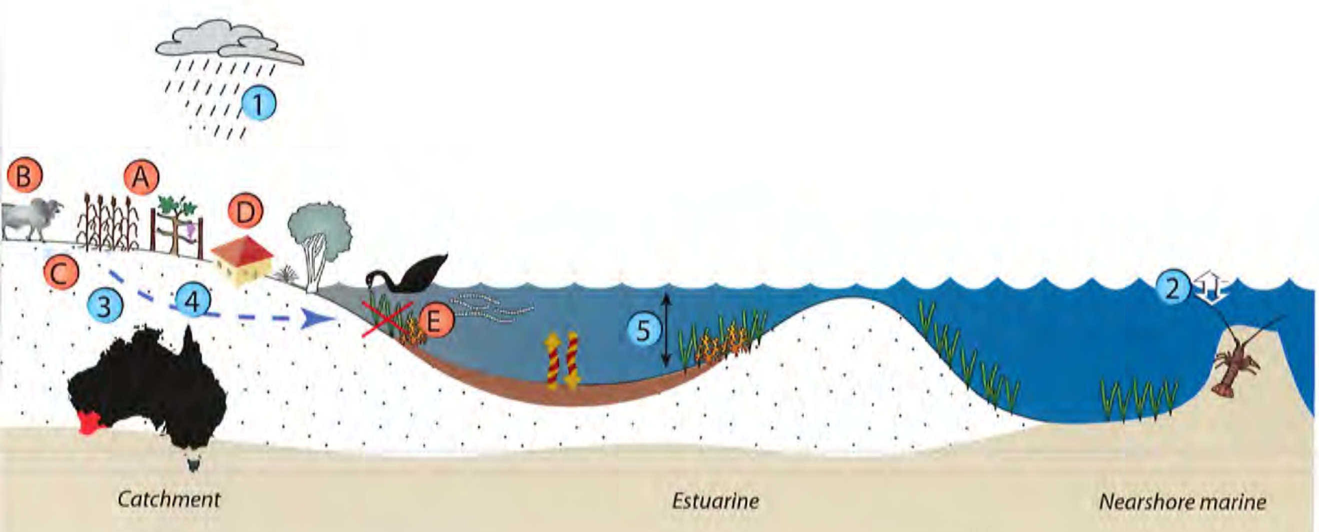
1. Mediterranean climate
2. Microtidal, wave-dominated systems
3. Flat, sandy catchments with poor nutrient holding capacity
4. Groundwater inputs
5. Shallow estuarine basins

Major Threats

A. Agriculture (wheat, vines)
B. Grazing
C. Salinity
D. Population pressures
E. Eutrophication: seagrass loss and algal blooms

Management Arrangements

Water and Rivers Commission, Western Australia



Pilbara and Subtropical West Coast

These estuaries, from the De Grey River south to the Greenough River occur along an arid to semi-arid coastline. Scattered summer thunderstorms and occasional tropical cyclones provide almost all the rainfall. The rivers rarely run to the sea and exist for much of the time as strings of waterholes in dry, sandy watercourses. During the infrequent wet seasons, the rivers empty directly to the coast but for much of the time there is marine penetration of river mouths and onshore sediment delivery. The tide range is large along the Pilbara coast (around 4 m) but is lower further south. Catchments are mostly hilly, with several iron-rich ranges present further inland.

Pilbara coastline

These rivers and estuaries are fragile ecosystems that are highly susceptible to upset by human activities. Catchments are widely grazed by sheep and cattle, and mining, particularly of iron ore, is a significant industry. Export ports for the iron ore industry at Port Hedland and Dampier/Cape Lambert are among the busiest ports, by tonnage, in Australia. The Port Hedland saltworks export some 2 million tonnes per year. Irrigated agriculture and horticulture occur further south, where rainfall is slightly higher. The northern wheat belt extends right to the coast near Geraldton.

Key Features

1. Arid coastline: occasional severe storms and cyclones
2. Tide-dominated: up to 4 m
3. Marine water penetration during dry periods creates inland deltas
4. Very high evaporation rates
5. Fluvial inputs are sporadic

Major Threats

A. Grazing (cattle)

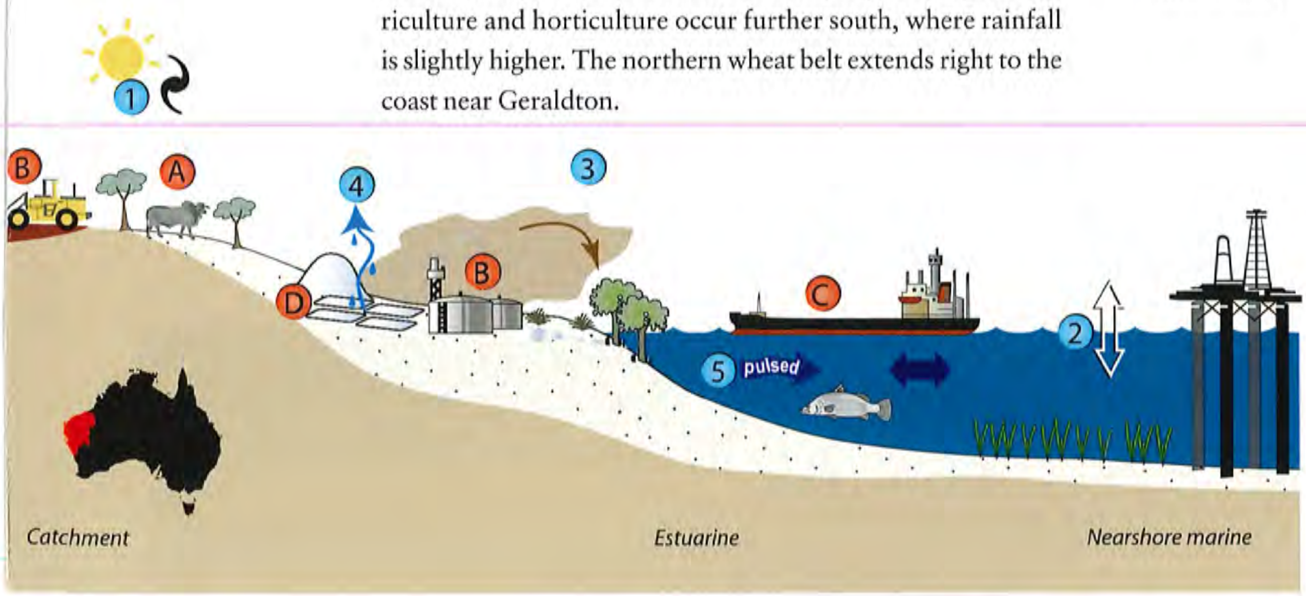
B. Mining and industrial development

C. Ports for onshore and offshore mining

D. Salt works

Management Arrangements

- Indigenous land management
- Port authorities
- Poorly understood systems - future research necessary



Kimberley Coast

The Kimberley region in northwestern Australia extends from the Cape Leveque Coast to the Daly River estuary. Estuaries here experience massive tides up to 12 m in places. Upper catchments are rugged and rocky, with many steep escarpments and waterfalls. The lower reaches of several rivers meander across vast floodplains to the Timor Sea. The climate is tropical with extreme wet/dry seasons and much variation from one year to the next.

King Sound near Derby shows the typical landscape created by the extreme tides in the Kimberley region.

Many estuaries have fringing mangrove forests and large areas of saltflats. On the larger rivers, seasonal wetlands on river floodplains are an important feature. Kimberley estuaries are important breeding and habitat areas for saltwater crocodiles. They also provide important habitat for waterbirds. The Kimberley region is remote and sparsely settled, with almost half the resident population Aboriginal. Most Kimberley estuaries remain in near-pristine condition, though the larger rivers have all been impacted to some extent.

Tourism, agriculture, cattle grazing, mining and fishing are the major industries. Development of irrigated agriculture and horticulture has centred on the Ord River floodplain. Mining occurs on the Kimberley plateau and there is exploration for alluvial diamonds in several estuaries. Tourism and charter fishing are economically important, and aquaculture ventures are planned for some estuaries.

Key Features

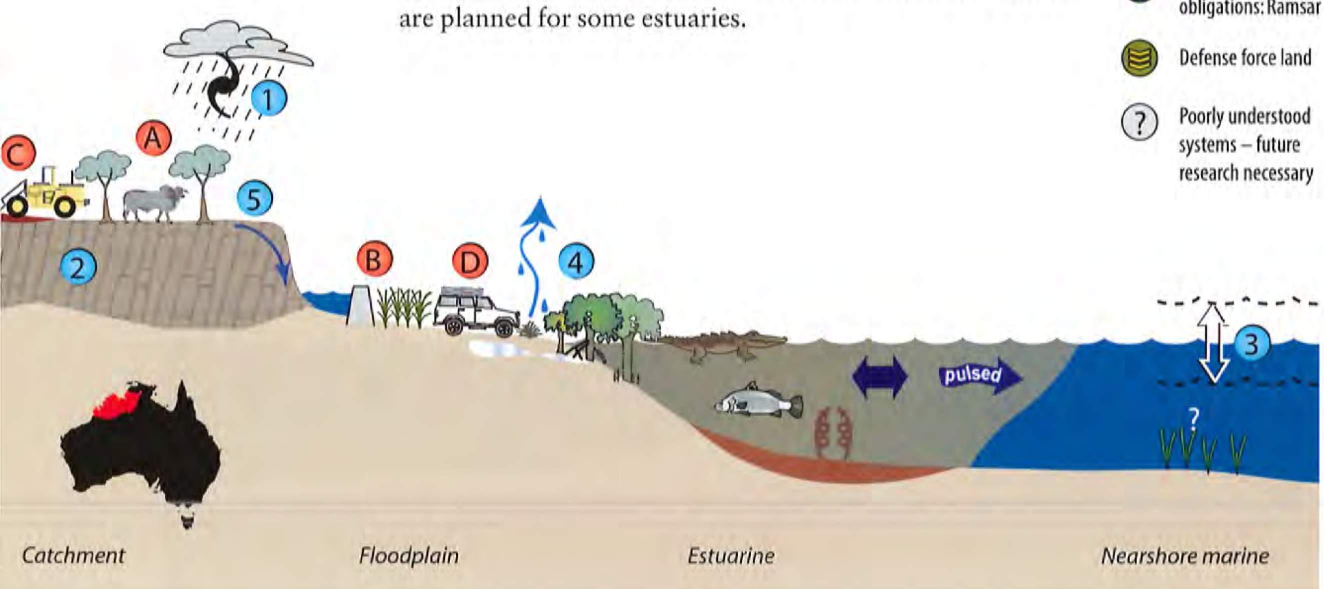
1. Monsoonal rainfall and cyclones with extreme wet/dry seasonality
2. Rocky catchments
3. Macrotidal (tide range greater than 10 m in areas)
4. Saltmarsh/saltpan and relatively diverse mangrove communities
5. Fluvial inputs are sporadic

Major Threats

- A Grazing (cattle)
- B Expansion of irrigated agriculture
- C Mining
- D Safari tourism

Management Arrangements

- Indigenous land management
- International obligations: Ramsar
- Defense force land
- ? Poorly understood systems – future research necessary



The Top End

The Top End region includes the northern coastline of the Northern Territory, from the Finnis River to the Gove Peninsula. Freshwater flows are highly seasonal, depending on the summer monsoon. Rivers flow north to the Arafura Sea, and are associated with extensive tidal and freshwater wetlands and floodplain systems that provide a haven for wildlife. Diverse and extensive mangrove forests fringe coastal creek systems and the meandering channels of the larger estuaries. On the floodplains are grasslands, saltflats, woodlands or sparsely vegetated cracking clays.

Except for the Darwin region and Nhulunbuy in the north-east, few people live along the coastline. A large part is remote and inaccessible by land. Significant areas of coastline are Aboriginal land, and the population in remote areas consists of Aboriginal communities and pastoral property homesteads.

A near-pristine estuary at Coburg Peninsula

Estuaries here are valuable for commercial and recreational fisheries, traditional harvesting and ecotourism. The dominant and often only land use in the catchments is grazing, with large-scale mining in some areas. Saltwater intrusion has damaged large areas of freshwater wetlands in the Mary River system. The warm, clean waters of Northern Territory estuaries have been targeted for aquaculture in the near future and expansion of sugar and cotton industries in top-end catchments is proposed.

Key Features

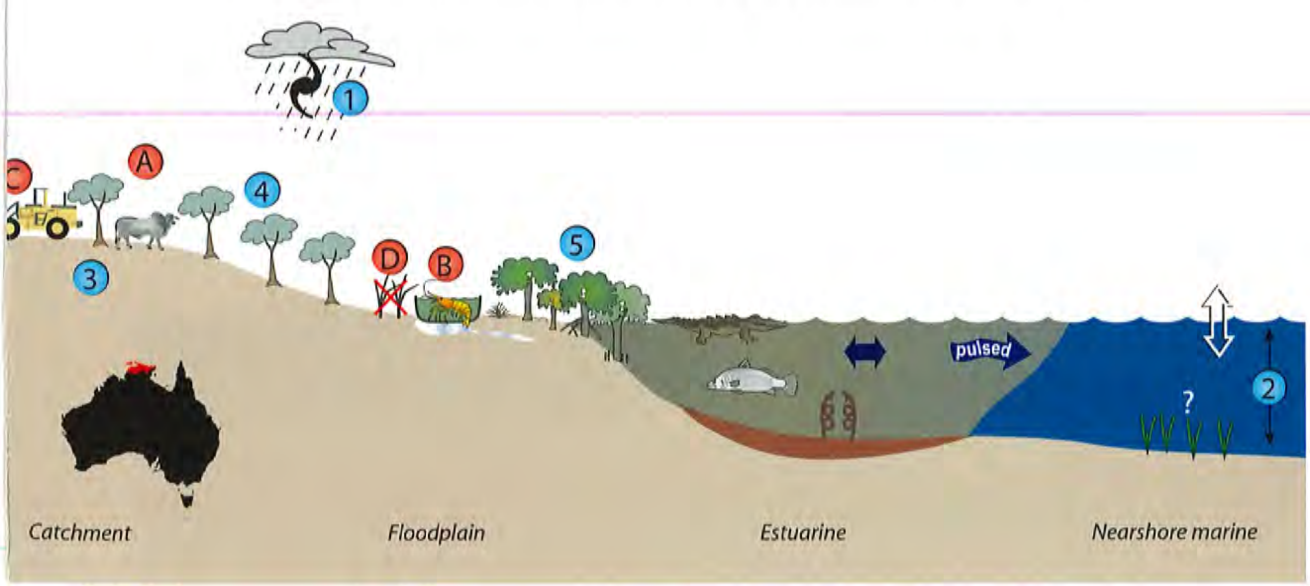
1. Monsoonal rainfall and cyclones
2. Shallow offshore areas
3. Flat, sandy catchments with little run-off
4. Relatively intact, sparsely populated catchments
5. Extensive mangrove habitats

Major Threats

- A Grazing (cattle)
- B Expanding aquaculture industry
- C Mining
- D Saltwater intrusion into coastal wetlands

Management Arrangements

- Indigenous land management
- ? Poorly understood systems – future research necessary



Gulf of Carpentaria

Rivers flowing to the vast, shallow Gulf of Carpentaria drain low-lying catchments with expansive floodplains. Rainfall is moderate but very variable. Almost all is brought by the summer monsoon. Tropical cyclones are common. Many of these form in the Gulf itself. The tide pattern of the Gulf is unusual, with most estuaries experiencing only one tidal cycle per day.

Norman River floodplain

The floodplains contain shallow seasonal and intermittent swamps and deeper waterholes and billabongs. Along the coastal fringe are fan shaped tidal wetlands that drain into the Gulf. These wetlands are habitat for fish, birds and estuarine crocodiles. Mangroves occur along much of the coastline and fringe the river channels, providing critical habitat for juvenile banana prawns. There are also vast areas of saltmarshes and saltflats. Diverse and extensive seagrass communities form an important habitat for juvenile commercial prawns. Large areas of the Gulf coast are Aboriginal land and Indigenous people fish many of the estuaries. Low-density grazing is the dominant catchment land use, and mining also occurs in some catchments. The commercial prawning and barramundi fishing industries are centred on Karumba on the mouth of the Norman River. Most Gulf estuaries are in near-pristine condition.

Key Features

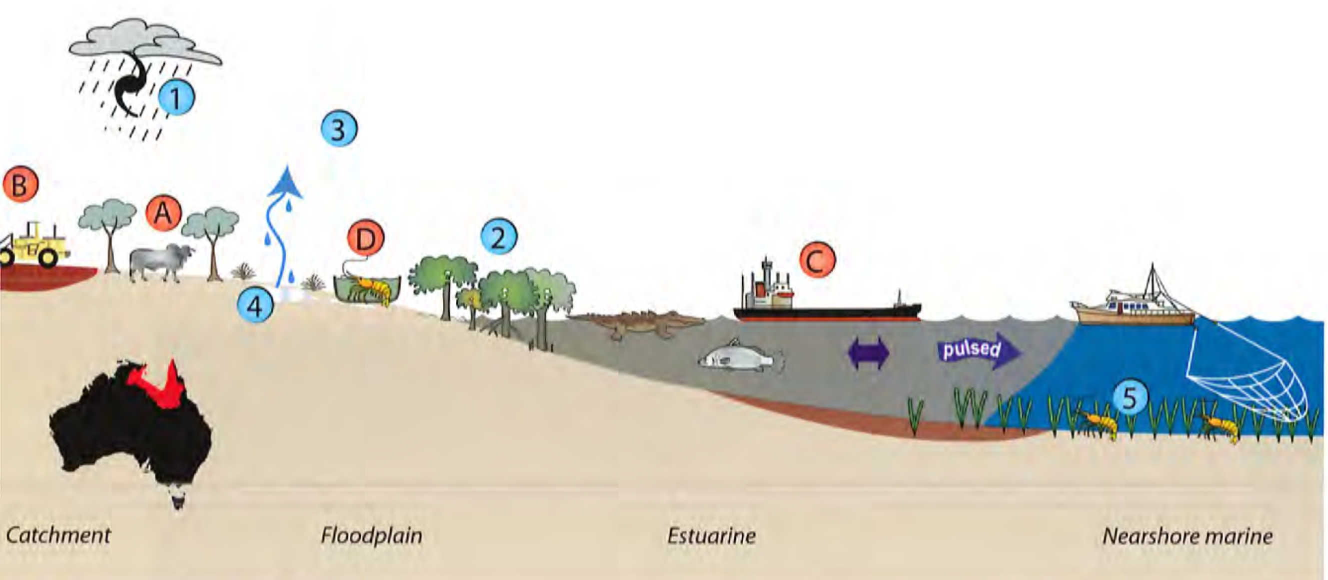
1. Monsoonal rainfall and cyclones
2. Diverse mangrove communities
3. Expansive floodplains
4. Salmarsh and saltpans
5. Gulf prawn fishery

Major Threats

A. Grazing (cattle)
B. Mining
C. Ports and shipping
D. Expanding aquaculture industry

Management Arrangements

- Indigenous land management
- Regional marine planning process about to commence
- (?) Poorly understood systems – future research necessary



Great Barrier Reef – Wet Tropics

Lizard Island National Park, Queensland

Most estuaries from the tip of Cape York to the Herbert River have short, coastal catchments with moderate to very high rainfall. Typically, freshwater flows all year round to estuaries despite rainfall being very seasonal. Fairly high tidal and river energy make for turbidity and strong currents. Severe tropical cyclones affect the area. Diverse and productive mangrove forests, often with rainforest elements, typically fringe these estuaries.

Seagrass is restricted by the high turbidity, but is found in shallow water near the mouths of several estuaries. During floods, turbid freshwater plumes can affect nearshore seagrass and coral reef communities. North of the Daintree River, most estuaries are near pristine. Grazing is the dominant land use. Cane farming on the coastal plain is the main land use south of the Daintree.

Clearing streamside vegetation increases sediment instream and reduces fish habitat. Commercial and recreational fisheries include barramundi, mud crabs and banana prawns. Aquaculture, particularly prawn production in coastal ponds, is an expanding industry. Tourism is increasing in the region, and four-wheel drive access and camping cause localised impacts. Several catchments are protected in the Wet Tropics World Heritage Area.

Key Features

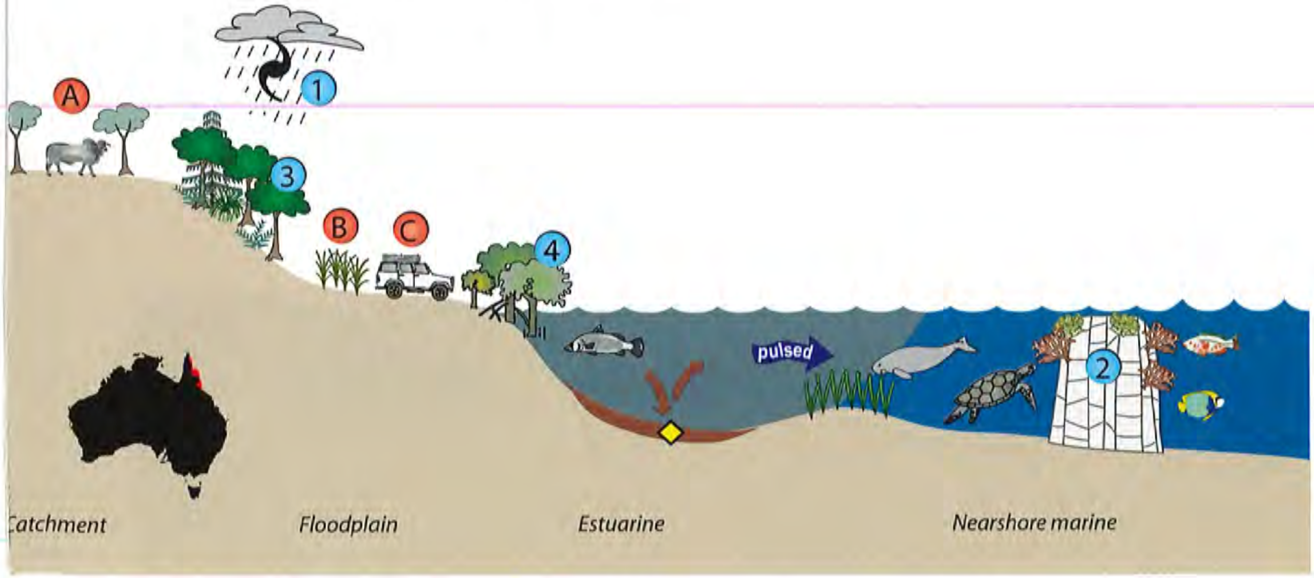
1. Annual monsoonal rainfall and cyclones
2. Inshore Great Barrier Reef
3. Steep, vegetated catchments
4. Diverse mangrove communities

Major Threats

- A Grazing (cattle)
- B Agriculture (cane)
- C Safari tourism

Management Arrangements

- International obligations: World Heritage, Ramsar
- Indigenous land management
- Regional agreements: CYPLUS



Great Barrier Reef – Dry Tropics

Catchments from Ingham south to Port Curtis have strongly seasonal rainfall and are much drier than those further north. The floodplains of these systems are larger than in the tropics and two large river basins, the Burdekin and the Fitzroy, drain extensive inland areas. Tidal energy dominates along the central Queensland coast but extreme rainfall events every few years can cause massive floods that flush sediment offshore. Tidal areas support vast mangrove communities. There are brackish and freshwater swamps on river floodplains.

Floodplain and riparian areas are often degraded or threatened due to clearing for agriculture and invasion by exotic species including ponded pasture grasses. Cane farming is the main land use on the coastal plain. Beef cattle grazing occurs in most other catchment areas.

Burdekin River

Several river systems have been affected by alterations to flow. These alterations include diversions, artificial aquifer recharge, and the construction of flow-modifying structures such as dams and barrages.

Tidal flats support prawn aquaculture and future expansion is proposed. Estuaries in this region are popular for recreational fishing and boating and are fished commercially. Several important Fish Habitat Areas are present.

Key Features

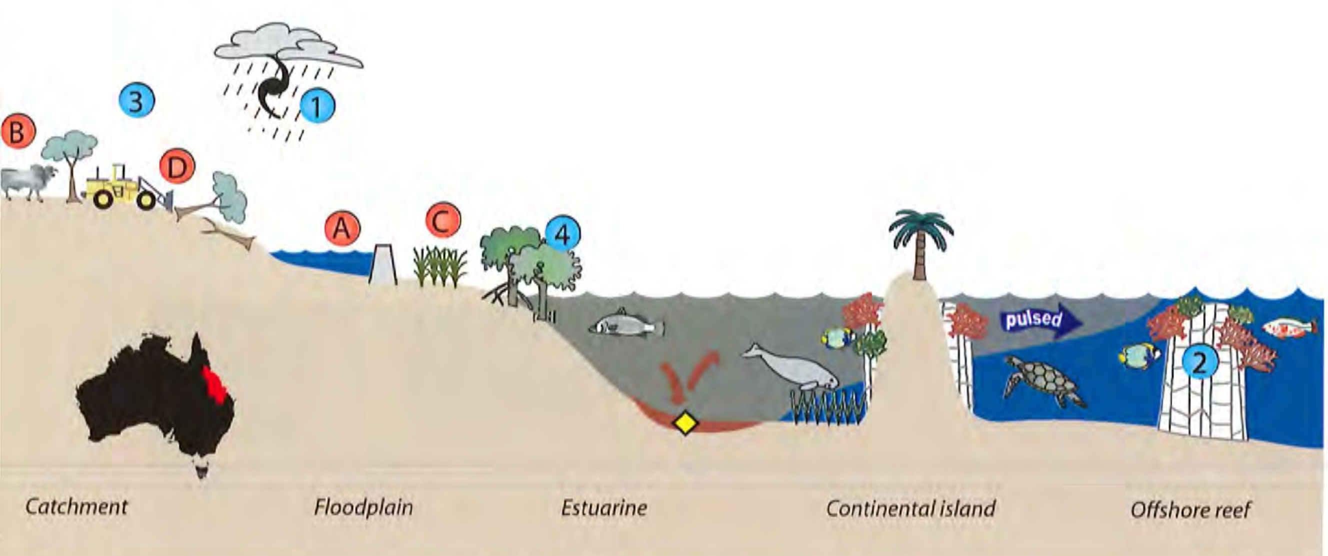
1. Inter-annual rainfall (ENSO), cyclones and pulsed run-off
2. Offshore Great Barrier Reef
3. Large catchments and floodplains
4. Extensive mangrove areas

Major Threats

- A Impoundments (irrigation)
- B Grazing (cattle)
- C Agriculture (cane)
- D Land clearing

Management Arrangements

- International obligations: World Heritage, Ramsar



Subtropical East Coast

From Port Curtis south to the New South Wales border, the coastline is no longer influenced by the Great Barrier Reef. Rainfall is more consistent in the catchments of this region than in the dry tropics. The summer and autumn months are much wetter.

Great Sandy Strait, Queensland

There is much diversity in the way these estuaries function. This is due to local variations in rainfall, tide and wave energy, and to the presence of a number of offshore dune barrier islands. These islands form the outer boundaries of two large estuarine embayments, Hervey Bay and Moreton Bay, which have extensive intertidal and shallow water habitats.

The subtropical east coast is a biogeographical overlap zone. It is the southern limit for tropical species and the northern limit for those with temperate affinities. A diversity of estuarine habitats supports important recreational and commercial fisheries and provides summer feeding areas for wading birds migrating down the Australasian flyway from the northern hemisphere.

Large areas of seagrass provide food for dugong and turtle populations. The region is heavily urbanised, and is one of the fastest growing areas in Australia. Urban pressures include habitat loss, stormwater and sewage discharges, extractive and navigational dredging and expanding port facilities. These have heavy impacts on many estuaries. Upper catchments are used for cattle grazing and crops.

Key Features

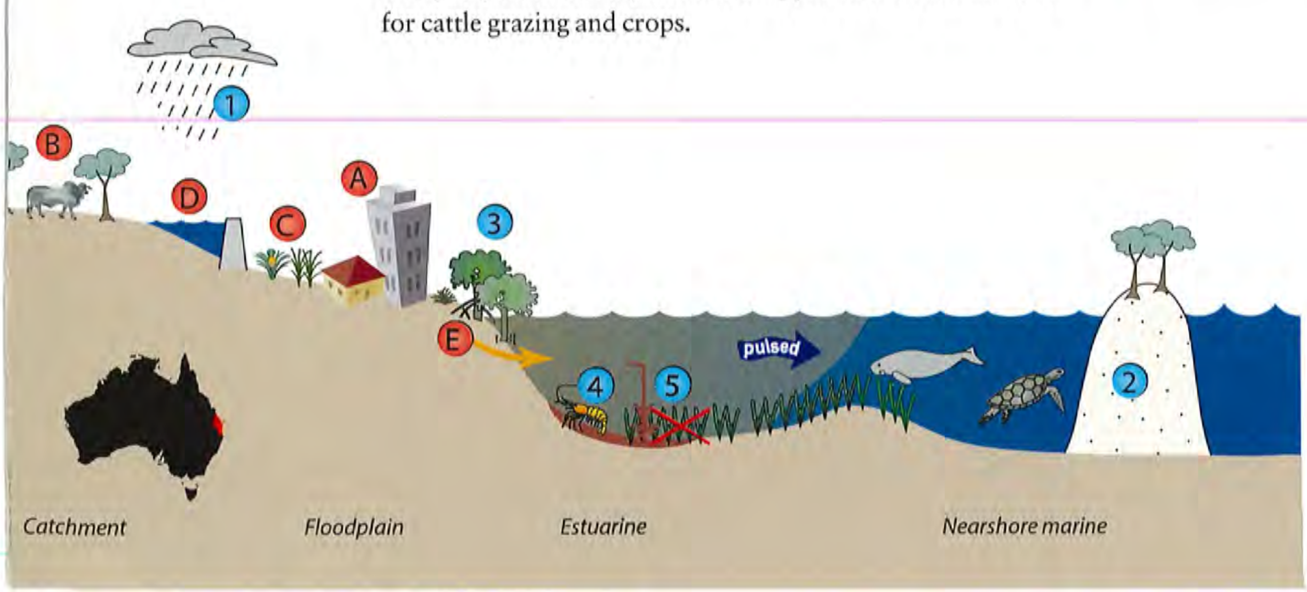
1. Dominant summer rainfall
2. Littoral drift: sand barrier islands
3. Fringing mangroves and saltmarsh
4. Prawn fishery
5. Turbidity/seagrass interactions: seagrass decline

Major Threats

- A Population growth – urban run-off, sewage, canal estates
- B Grazing
- C Agriculture (diverse)
- D Impoundments (domestic water, flood mitigation)
- E Acid sulfate soils

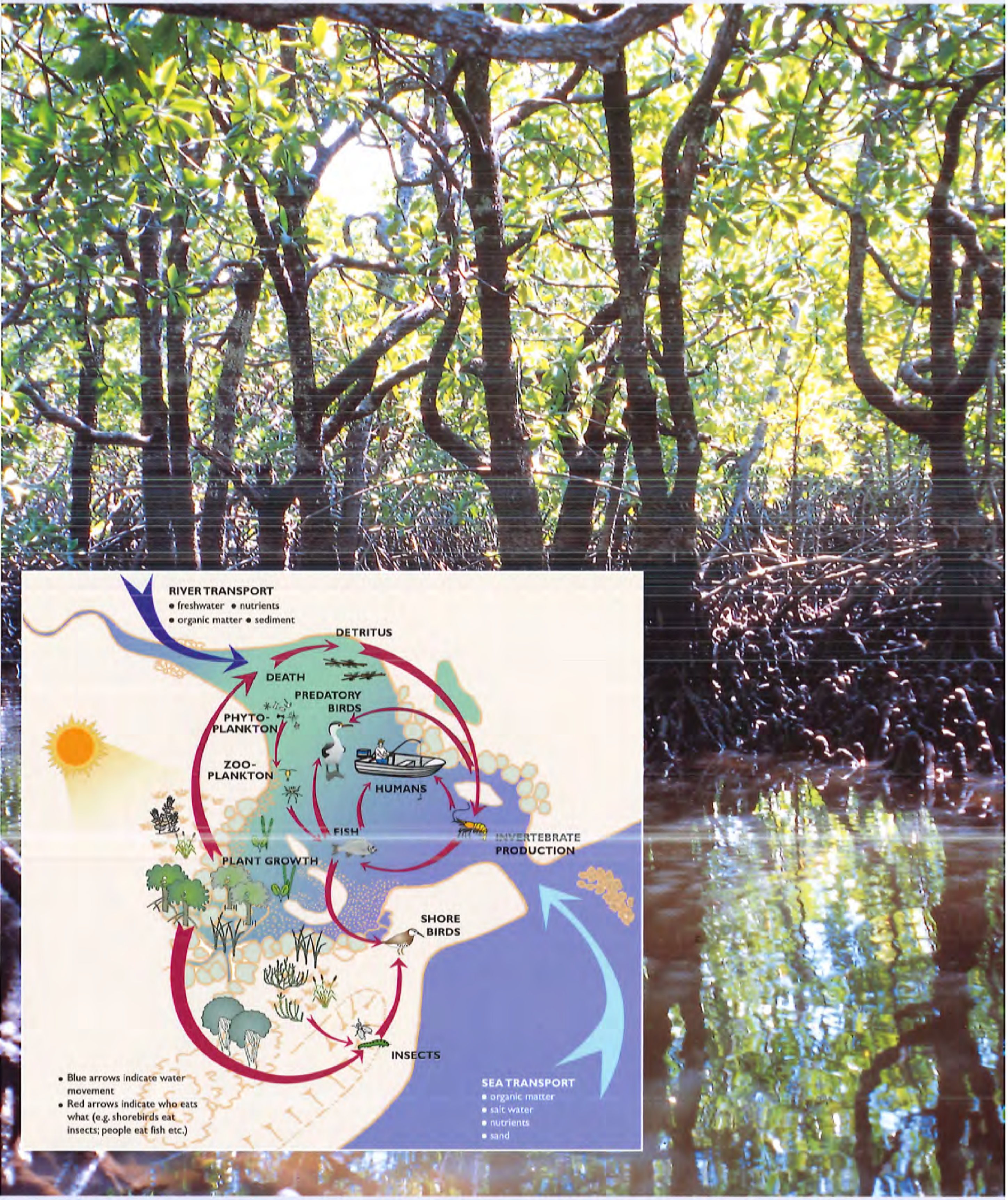
Management Arrangements

- International obligations: Ramsar
- Regional agreements: MBWP



chapter 3

Estuary habitats


RIVER TRANSPORT
• freshwater • nutrients
• organic matter • sediment
DETRITUS
DEATH
PREDATORY BIRDS
PHYTO-PLANKTON
ZOO-PLANKTON
HUMANS
FISH
INVERTEBRATE PRODUCTION
PLANT GROWTH
SHORE BIRDS
INSECTS
• Blue arrows indicate water movement
• Red arrows indicate who eats what (e.g. shorebirds eat insects; people eat fish etc.)
SEA TRANSPORT
• organic matter
• salt water
• nutrients
• sand

Estuaries are difficult places for animals to live. Because of their variable conditions of saltiness, temperature, and water level and their confinement to small, transitional areas between land and sea, estuaries tend to support fewer animal and plant species than marine or freshwater ecosystems. Nevertheless, animals that can cope with these conditions thrive there. Nutrients carried in from the ocean and the river make estuaries very fertile areas for plant growth. In fact, they are among the most biologically productive ecosystems on Earth. Primary productivity (the rate at which plants convert the sun's energy by photosynthesis into food that animals can use) is higher in many estuaries than in grasslands, forests and even cultivated farmland.

Relatively few animals (e.g. black swans, dugongs, green turtles) feed directly on living plant material in estuaries. Rather, as estuarine plants die and decay, the dead plant material (detritus) is eaten by a rich assortment of microscopic bacteria, fungi, protozoa and other micro-organisms. This protein-rich mix along with the detritus, is then consumed by small animals such as worms, snails, clams, oysters, and juvenile fish and prawns. These detritus eaters (detritivores) are then eaten by fish and birds, which in turn are eaten by larger fish, birds and mammals and so on up the food chain. Many higher predators (e.g. pelagic fish such as queenfish and trevally) move *en masse* into estuaries to feed at specific times of the year.

Tropical mangroves, Hinchinbrook Island

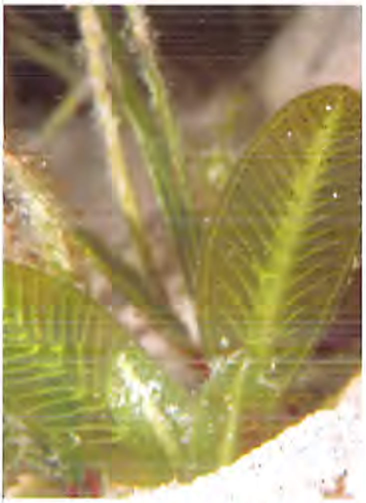
Inset: A typical estuary food web

The regular incoming tides replenish the supply of oxygen for animals that feed in estuaries. Outgoing tides carry away their wastes, which are used elsewhere in the estuary and nearby ocean. The survival of many species, even predators that rarely visit estuaries, depends on populations of fish and birds that use these coastal ecosystems at key times in their life cycles.

Estuary habitats

- *Seagrass*
- *Mangroves*
- *Saltmarsh*
- *Melaleuca swamps*
- *Open waters*
- *Muddy and sandy basins*
- *Coastal floodplains*
- *Intertidal mudflats*
- *Coral*
- *Sandy shoals and beaches*
- *Rocky shores and reefs/ macroalgae*

Seagrasses



Halophila ovalis, Moreton Bay, Qld

Typical seagrass flora and fauna (below right);

Sea anemone with commensal shrimp feeding within a Halophila spinulosa habitat (below)

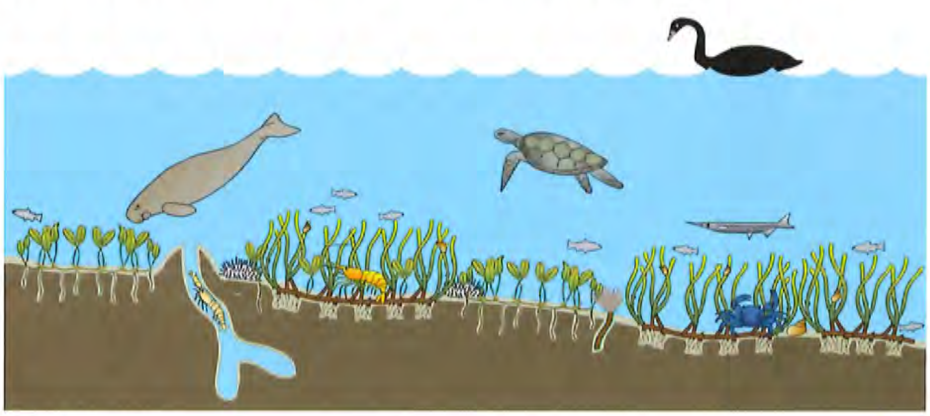
Seagrasses are flowering plants (angiosperms) that grow rooted in soft sediments of marine and estuarine environments. Productivity of individual species varies, but on the whole they are productive, widespread and ecologically vital to nearshore environments. Our 32,000 km coastline has the world's largest and most diverse seagrass assemblages.

Seagrasses in Australia can be divided into those with temperate and those with tropical distributions, with the greatest diversity occurring where the zones overlap (e.g. Shark Bay in Western Australia).

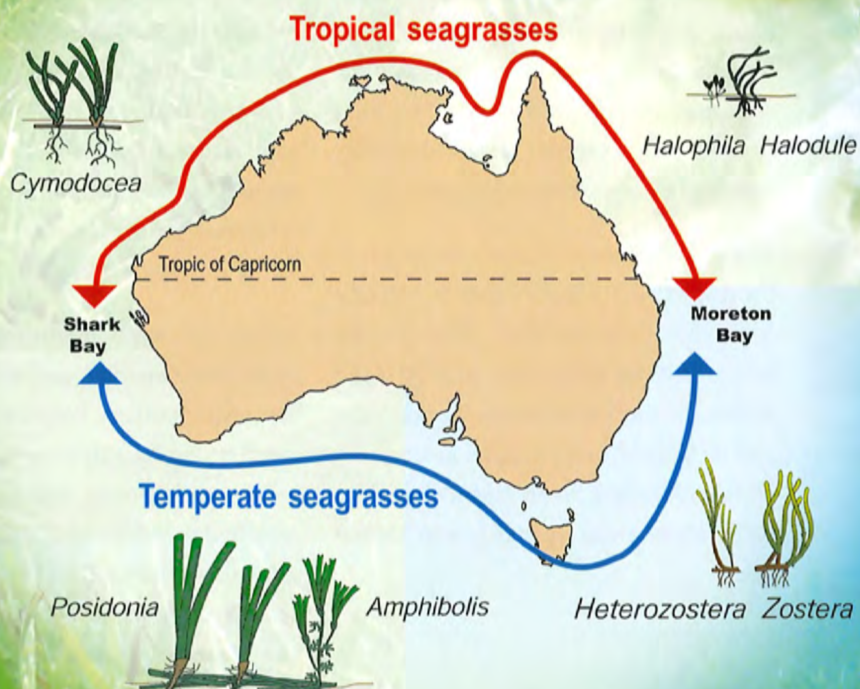
Seagrass areas are highly productive, meaning that they produce a lot of new plant material that supports large populations of animals. Still, only a few types of animals eat living seagrass. Dugongs and turtles graze certain tropical species. Seagrass is also eaten by sea urchins and other invertebrates (e.g. amphipods, snails), by some fishes (e.g. garfish, luderick and leatherjackets) and birds (e.g. black swans, ducks and geese). Most of the organic matter and nutrients that support seagrass food webs originates as detritus. Vast populations of bacteria and fungi decompose the seagrass litter. These, in turn, are eaten by small animals which form the base of the predatory food web.

Intact seagrass beds help keep the seafloor stable, slow currents and reduce water turbulence. In this quiet place, suspended sediments settle, erosion is limited and fauna find safe haven. Seagrass stems and leaves are relatively hard surfaces colonised by many life forms, such as algae, bryozoans and hydroids. The biomass of algae on seagrass may exceed that of the seagrass itself, making it a very important primary producer in the food web. Seagrass beds support many sponges, anemones, bivalves, polychaete worms, starfish, sea cucumbers and crustaceans. Cuttlefish, squid and a large number of fish species are predators in seagrass beds.

Because they protect and feed juvenile fish and crustaceans, seagrass beds are vital for a variety of coastal fisheries around Australia. Some fish live in seagrass beds for their entire life cycle, some species spend their juvenile stage here and others come and go with the tides.



Tropical seagrass fauna – dugong , cuttlefish, leatherjacket

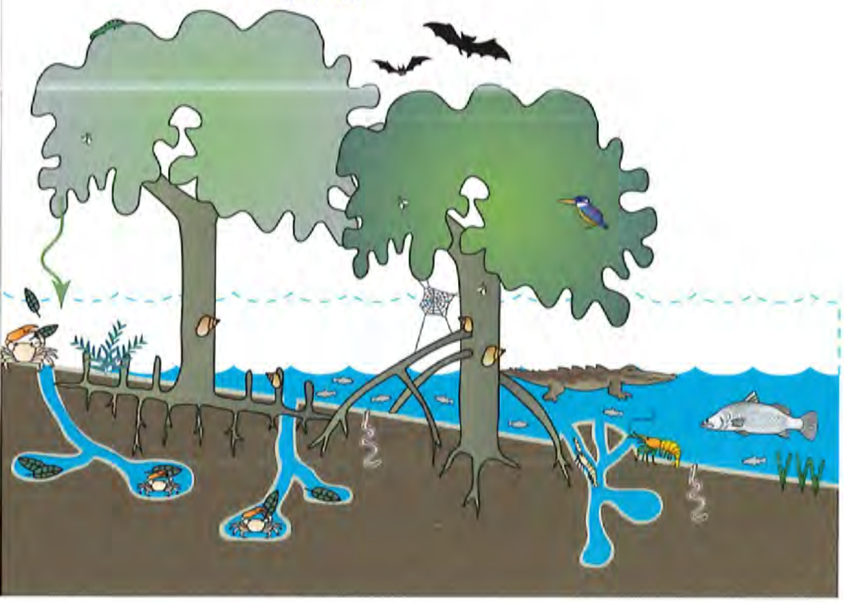


Seagrass beds, clockwise from top left:
Cymodocea serrulata *(foreground)*,
Syringodium isoetifolium; Halophila ovalis;
Amphibolus griffithii; Posidonia australis

Mangroves

Seedling of Avicennia marina

Typical mangrove flora and fauna (below)



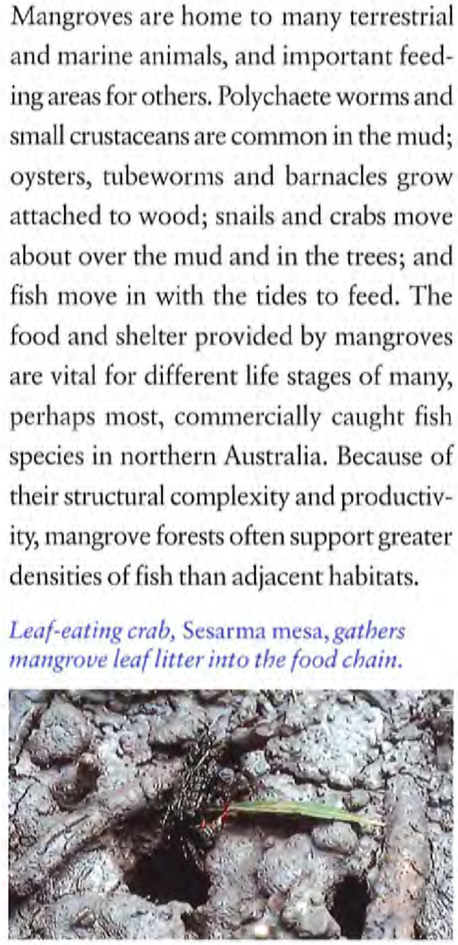
Mangroves are trees and shrubs that usually grow in soft sediments in the intertidal zone. They are specialised in a number of ways to cope with waterlogged soils deprived of oxygen and nutrients, and high levels of salt in the water. Extensive, though shallow, root systems help anchor the plant, and many mangroves have aerial roots (pneumatophores) that let them 'breathe'. The seeds of many mangrove species germinate while still on the parent tree. This allows them to establish rapidly without being washed away by the tide.

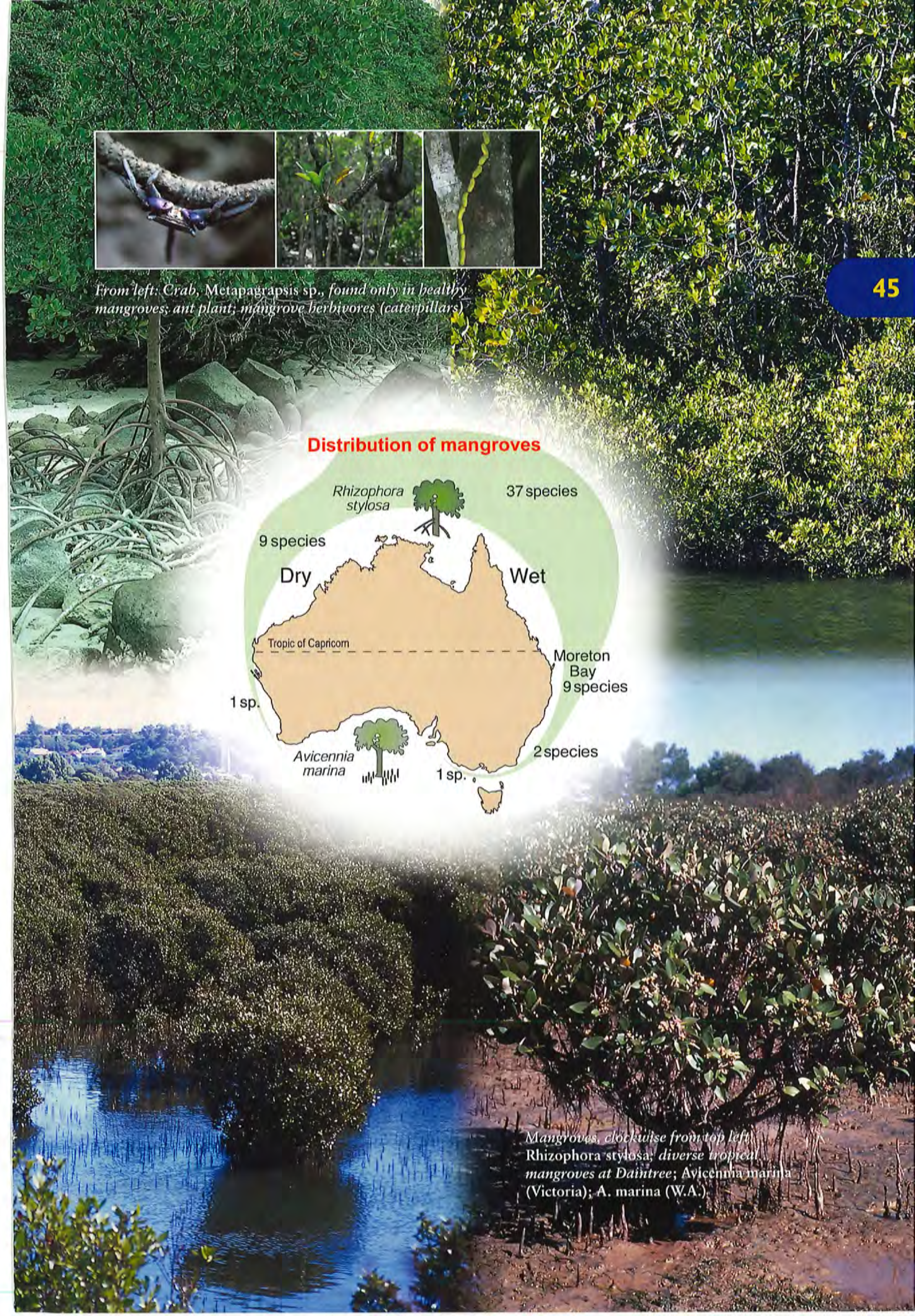
Mangrove diversity reaches its zenith in the tropics, with some 37 species, and falls away rapidly to the south. The versatile grey mangrove (*Avicennia marina*) is the dominant species in temperate Australia and is the only species found in southern Western Australia, South Australia and Victoria. There are no mangroves in Tasmania.

Mangroves protect the coastal fringe from erosion, and trap sediments from overland run-off. Mangrove forests are very productive ecosystems. They provide nutrients and organic material to the food web in the form of litter (leaves, twigs, bark, fruit and flowers). Some is eaten by crabs and green turtles, but most is decomposed by bacteria and fungi. Larger particles are consumed by fish and prawns, while smaller particles are taken up by molluscs and small crustaceans. A considerable amount of detritus is also washed out from mangroves and provides an important source of food in many nearshore areas.

Mangroves are home to many terrestrial and marine animals, and important feeding areas for others. Polychaete worms and small crustaceans are common in the mud; oysters, tubeworms and barnacles grow attached to wood; snails and crabs move about over the mud and in the trees; and fish move in with the tides to feed. The food and shelter provided by mangroves are vital for different life stages of many, perhaps most, commercially caught fish species in northern Australia. Because of their structural complexity and productivity, mangrove forests often support greater densities of fish than adjacent habitats.

Leaf-eating crab, Sesarma mesa, *gathers mangrove leaf litter into the food chain.*





From left: Crab, Metapagrapsis sp., *found only in healthy mangroves; ant plant; mangrove herbivores (caterpillars)*

Mangroves, clockwise from top left: Rhizophora stylosa; *diverse tropical mangroves at Daintree;* Avicennia marina (Victoria); A. marina (W.A.)

Saltmarshes

Saltmarsh species at Andersons Inlet, Vic (above) and the Coorong, SA (below)

Saltmarshes are communities of low-growing herbs, shrubs and grasses tolerant of high salinity and poorly aerated soils. They occur in areas where tidal inundation is regular but infrequent. They often form a mosaic of vegetated, low-lying mounds bordering shallow pools or hypersaline saltpans and are sometimes drained by small creeks. Most saltmarsh plants belong to a few widespread families, including the grasses, saltbushes and their allies, rushes and sedges.

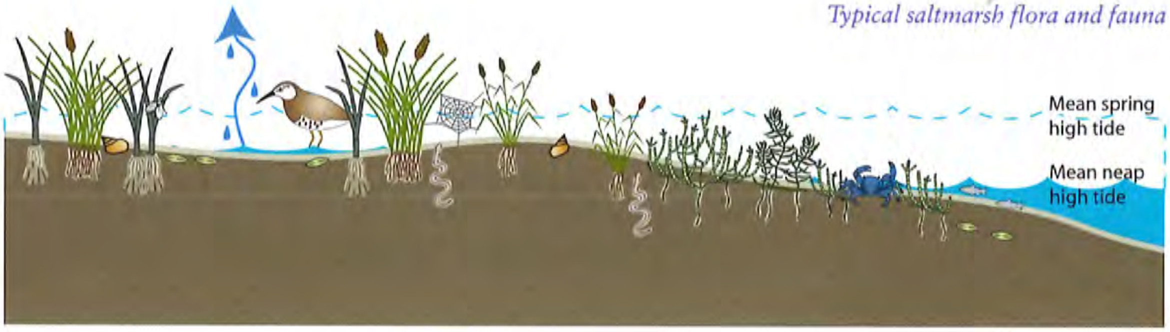
In contrast to mangroves, many more saltmarsh species are found in southern Australia than in tropical Australia. The plant communities of saltmarshes typically occur in zones from low to high elevation with each zone dominated by one species. For example, on the New South Wales coast, a typical order would be *Sarcocornia quinqueflora–Sporobolus virginicus–Juncus krausii.*

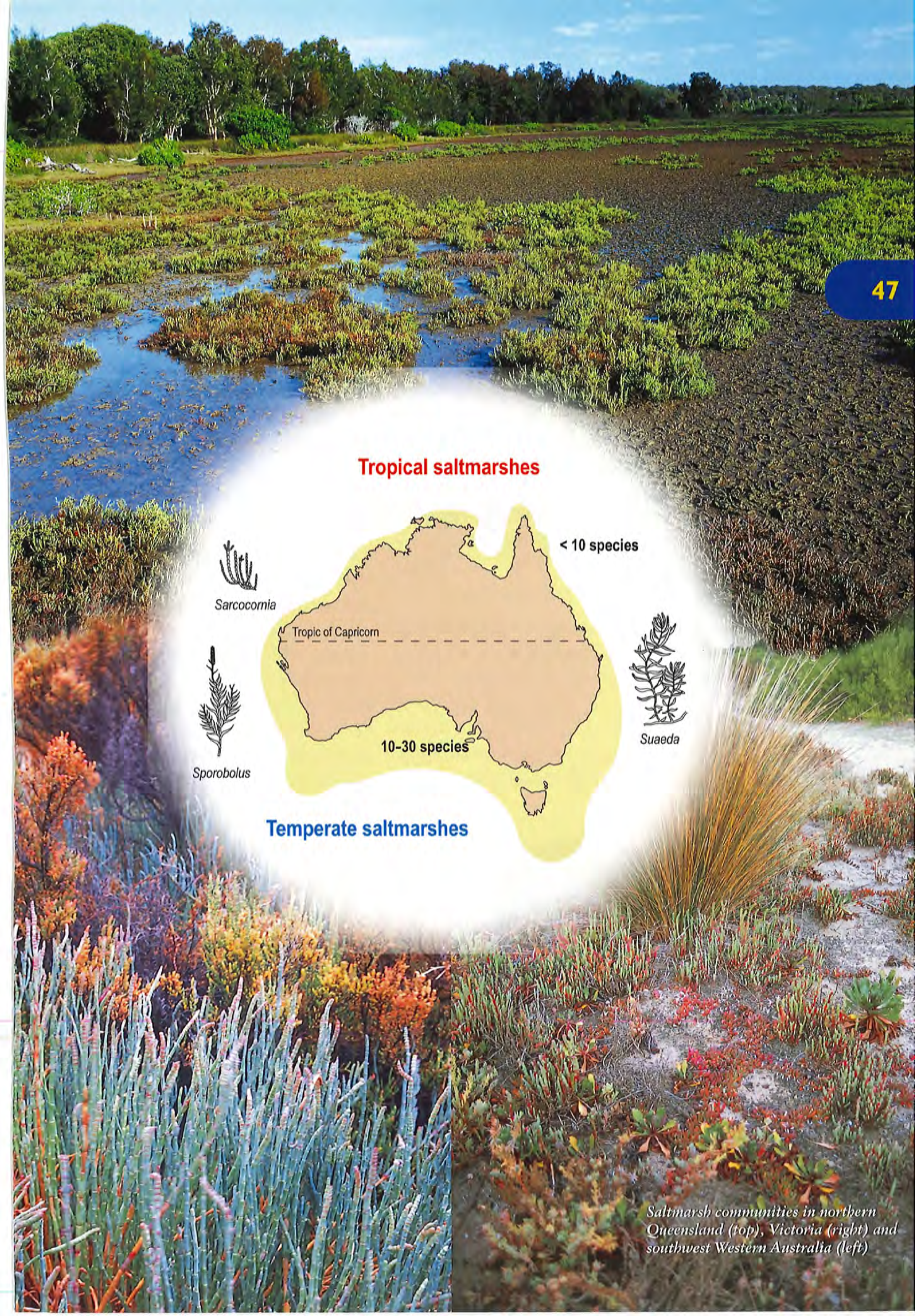
Saltmarshes help maintain estuarine water quality by filtering sediment from land-based run-off. They provide organic matter to estuarine food chains, but are not as productive as seagrass or mangrove areas, nor are the animal communities in saltmarshes as diverse as those of adjacent habitats. However, they provide important habitat for some fish and aquatic invertebrates and a range of terrestrial species including insects and their larvae, spiders and lizards. These attract waterbirds such as herons, bitterns, egrets, waders and some bush birds.

Tropical saltmarsh, Houghton River estuary, North Queensland

Saltmarshes are frequently covered by high tides and may support dense mats of algae that provide an additional food source for many fish and invertebrates. Shallow pools topped up intermittently by rain provide transitory feeding habitats for larval and juvenile fishes including several of importance to fisheries.

Typical saltmarsh flora and fauna





Saltmarsh communities in northern Queensland (top), Victoria (right) and southwest Western Australia (left)

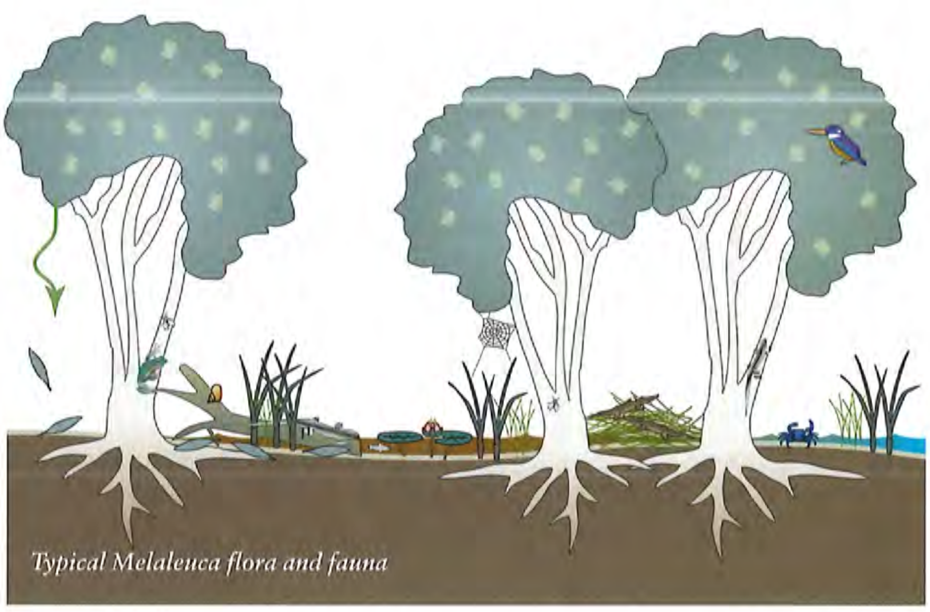
Melaleuca swamps

Melaleuca (paperbark) swamps are found in low lying areas adjacent to many estuaries, between terrestrial and tidal vegetation. There are vast freshwater paperbark swamps on the river plains of northern Australia but more salt-tolerant species are also associated with estuaries, forming brackish swamps adjacent to mangroves. They are also common in low-lying areas (swales) between beach ridges where water pools for prolonged periods. In southern Australia, *Melaleucas* sometimes fringe the shoreline of microtidal estuaries, where they are inundated infrequently by high tides.

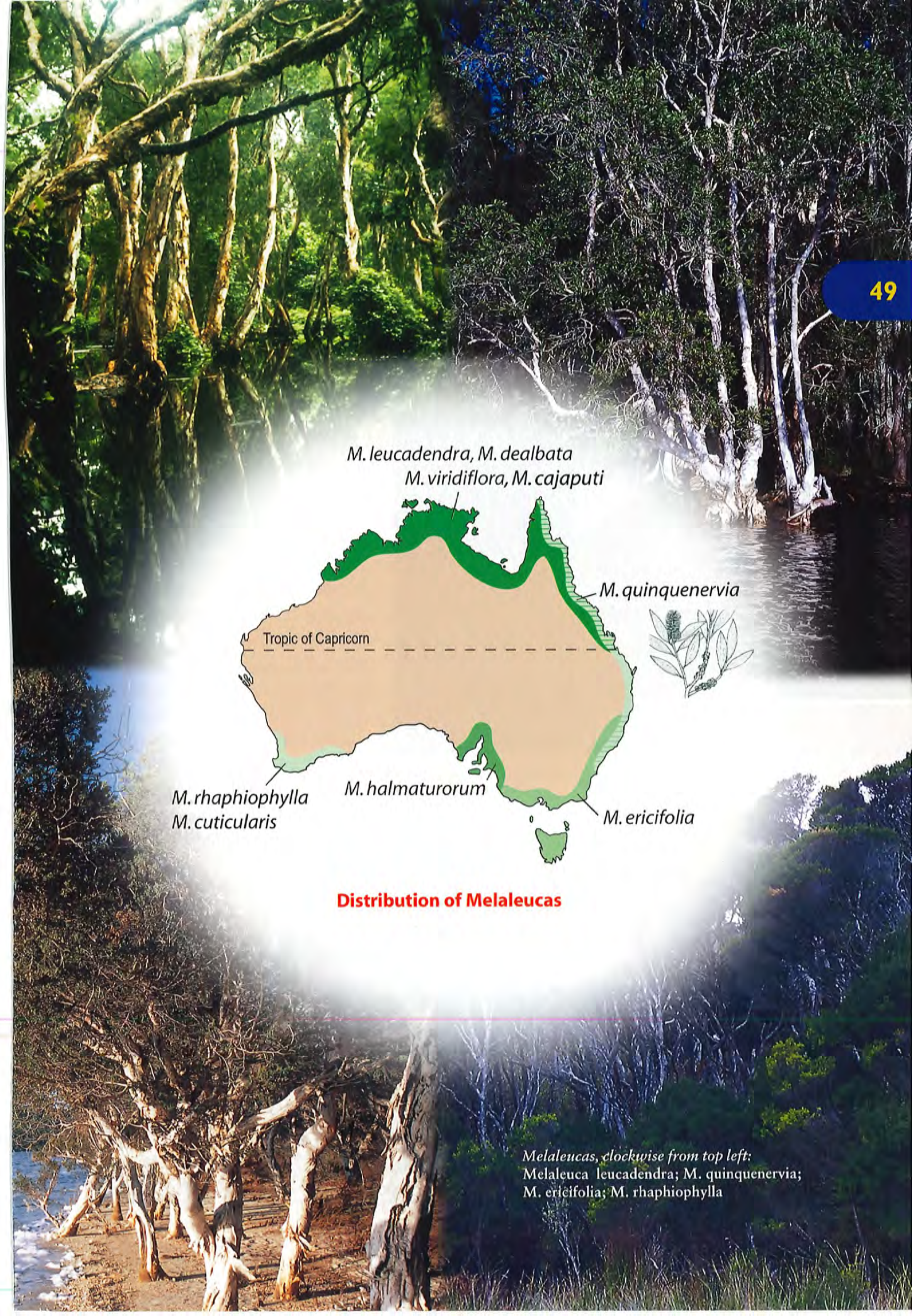
Melaleuca swamps can vary from open forests to woodlands and heaths. *Melaleucas* and other tree species in these communities are generally tolerant of brackish water and anaerobic soils. Certain *Casuarina* (she-oak) species and eucalypts such as swamp mahogany are typical, along with a diversity of other species in tropical areas. Sedges, grasses and aquatic herbs form an understorey in these areas. The swamps may be fresh or brackish but most are inundated with freshwater during floods. Their value as habitat lies not only in the physical structures they provide but also in their ability to absorb, store, and slow the release of floodwaters; to buffer the impacts of tidal waters; and to filter, process and export organic material and nutrients to adjacent habitats.

Melaleuca swamps provide organic matter to the estuary (as detritus) and contain many species of wildlife. *Melaleuca* flowers are an important food source for birds and bats. Several ground-dwelling mammals including the water rat and other native rats, and reptiles such as snakes and lizards also live in these swamps. In tropical Australia, Melaleuca swamps are nesting areas for estuarine crocodiles.

Melaleucas – Melaleuca rhaphiophylla *(top)*, Melaleuca quinquenervia *(above and below)*



Typical Melaleuca flora and fauna



Distribution of Melaleucas

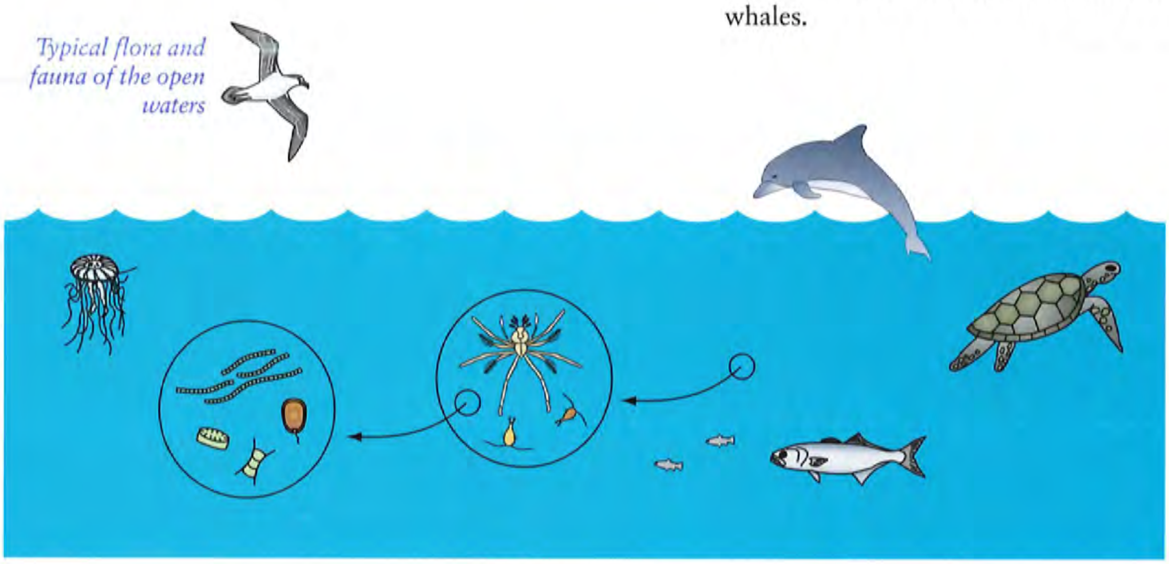
Melaleucas, clockwise from top left:
Melaleuca leucadendra; M. quinquenervia; M. ericifolia; M. rhaphiophylla

Open waters

The majority of life inhabiting the open waters of estuaries goes completely unnoticed by the casual observer. In fact, estuarine waters are teeming with life, but most of it is too small to be seen with the naked eye. The millions of tiny life forms that inhabit estuarine waters are collectively known as plankton. These include microscopic bacteria, plants and animals, and a range of single-celled creatures (protists) many of which are something between a plant and an animal. The phytoplankton (plant plankton), which includes cyanobacteria and photosynthetic protists, use light energy and simple chemicals in the water to grow and multiply. These are then eaten by a range of tiny animals and protists (the zooplankton) which provide food for larger zooplankton and so on up the food chain. In this way, the phytoplankton form the basis for the productivity of open estuarine waters. The zooplankton includes larval forms of many familiar animals including sea urchins, snails, crabs, lobsters and fish, as well as many species that spend their entire life as plankton. The open waters of estuaries serve as feeding grounds for pelagic fish such as tailor, fish-eating birds such as sea eagles, terns, gulls and cormorants, and mammals such as dolphins and even whales.

The open waters of estuaries are feeding grounds for many fish-eating marine animals

Typical flora and fauna of the open waters



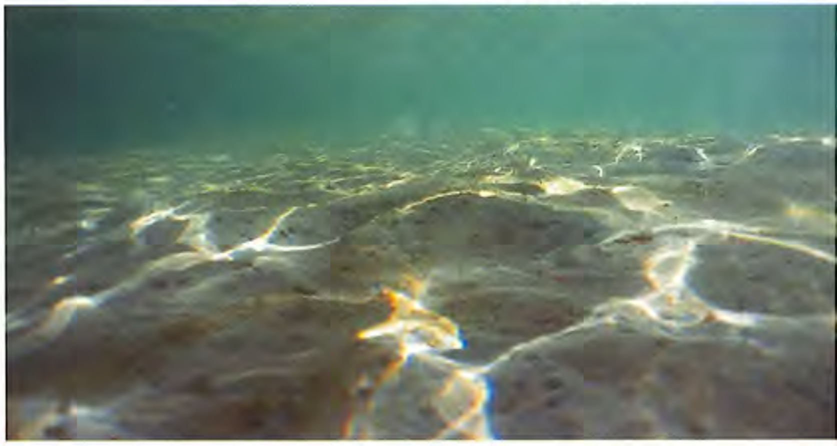
Muddy and sandy basins

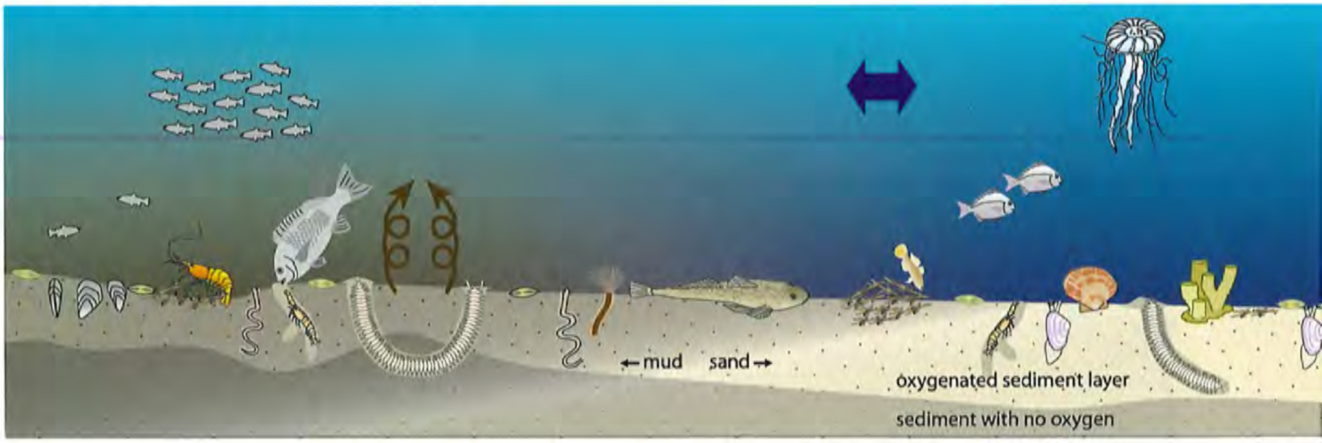
Unvegetated, or 'bare' sand or mud beds occupy the greatest subtidal area of many estuaries, but these areas are by no means uniform. Variation in the type of sediment (e.g. from marine sand to mud), saltiness, water depth, water movement and position in relation to other habitat types all strongly influence what lives in these areas.

Subtidal sandy bottoms are found in more exposed areas, particularly in larger bays. Muddy basins are associated with the sheltered conditions of many estuaries. Where enough light penetrates and the sediments are sufficiently stable, a range of microscopic algae live on the sediment surface. Many of these algae migrate up and down within the sediments to photosynthesise during the day and escape predators at night. Scavengers and organisms that feed on surface deposits dominate in unvegetated areas. Common invertebrates living in unvegetated muddy areas include prawns, bivalve molluscs, polychaete worms and small crustaceans. Prawns are opportunistic feeders that eat bacteria, algae and tiny animal species during their juvenile stages. When they mature, small molluscs, crustaceans and polychaete worms also form part of their diet. Prawns and other invertebrates are eaten by estuarine fish that live and feed in unvegetated areas. Juvenile fish also inhabit these areas, and may escape predation through schooling and camouflage, or because turbid conditions obscure them from predators. A different range of invertebrates is found in sandy areas. These include hydroids, seapens, bryozoans, sponges and molluscs such as scallops, as well as polychaetes and crustaceans. Fish such as flounder, flathead, whiting and sharks are also found on sandy bottoms.

Photosynthetic algae inhabit the 'unvegetated' sandy bottoms of estuaries in areas where enough light penetrates (below)

Typical flora and fauna of a sandy basin (bottom)





Coastal floodplains

Coastal floodplains are areas in the lower reaches of rivers that are partly covered by floodwaters and/or tides up to several metres above the high-water mark. In flat regions such as the Gulf of Carpentaria, the coastal floodplain can be very extensive. Large areas of low-lying floodplain are covered with water in periodic floods. Less extensive areas are covered with king tides and a smaller proportion is inundated by regular tides.

Rivers deposit nutrients and sediments onto floodplains during floods. Algae in soils become active when exposed to water. This may contribute to the productivity of the floodplain food web for example through nitrogen fixation. When floods evaporate, swamps and lagoons are formed. These include shallow marshes and deeper ponds and billabongs. These wetlands may be permanent or may flood only on an intermittent basis and disappear entirely during dry periods. Salinity often increases from freshwater to brackish or saline throughout the year.

Floodplain wetlands are important breeding areas, dry season refuges and migration stopover points for many bird species. Plants include grasses and sedges, *Melaleuca* species, waterlilies and other aquatic herbs. Floodplain communities are often bordered by eucalypt forests or woodlands, and saltmarsh or mangrove vegetation. Coastal floodplains are probably the most poorly understood ecologically of the coastal ecosystems.

Lakefield National Park marine floodplain

Intertidal mudflats

Intertidal mudflats are formed over a long period of time from deposits of fine silt and clay particles eroded from catchments. Gradual accumulation of particles in sheltered areas results in an almost flat, muddy shore extending some distance seaward from the high-water level. Mudflats are more common in tropical Australia, where greater river flows carry large amounts of fine sediments and organic material to the coast. Mudflats are poorly drained. They remain saturated with water at low tide. Bacterial decomposition of organic material takes oxygen from all but the top few centimetres of sediment, below which the mud is black and smells of sulfur due to anaerobic bacteria.

Few animals are able to survive in these anoxic conditions, so most of the fauna of intertidal mudflats is found in the top few centimetres of sediment where oxygen is available. In this layer, a diverse range of tiny, mostly microscopic animals inhabits the spaces between the sediments. The surface of the mud is also occupied by high densities of microscopic single-celled and filamentous algae, which help bind and stabilise the surface sediments. Larger invertebrates that live in burrows and tubes, such as ghost shrimps (yabbies), soldier crabs and tubeworms, are able to live much deeper in the mud as these burrows are more readily flushed with oxygen-rich seawater.

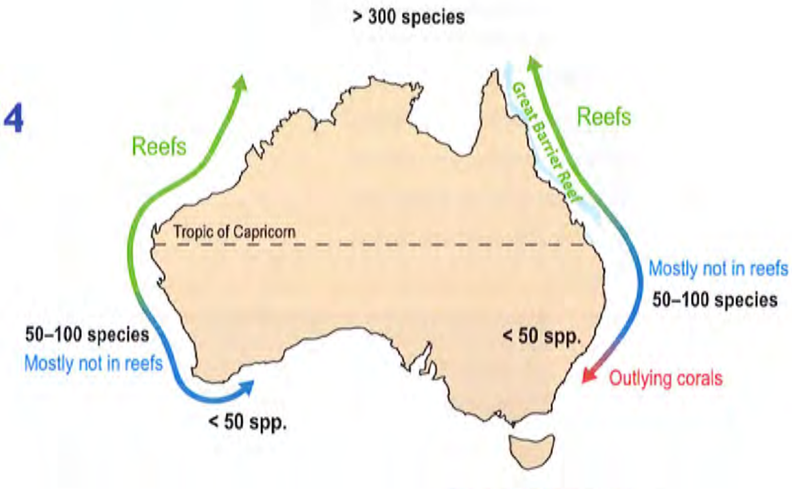
Animal activity on intertidal mudflats follows the tidal cycle. Fish track the edge of the incoming tide, moving into intertidal areas to feed. When the tide is in, detritus eaters and filter feeders are active. Crabs, birds and mudskippers pick off any animal too slow to find a hiding place as the tide recedes. People also use mudflats as a source of food and bait.

In northern Australia intertidal mudflats are vast, due to very large tides. They are some of the most productive intertidal systems on Earth. Rich pickings from these habitats draw migratory birds from across the world to our northern shores.

Mudflat with soldier crabs (top); soldier crabs close-up (above); white ibis (below)

Typical fauna of an intertidal mudflat

Coral



Coral distribution

Coral communities in Moreton Bay (below and below right)

Corals are not normally associated with estuaries. In general they are intolerant of freshwater, sensitive to turbidity and sedimentation and need a hard surface to colonise. Corals are tropical organisms, patchily distributed along temperate coastlines and almost entirely absent from Australia's southern coast. Most tropical estuaries present extremely poor conditions for coral establishment and growth.

Nevertheless, corals can be found in several estuarine bays such as Moreton Bay and Hervey Bay. Nearshore coral reefs along much of the Great Barrier Reef are also subjected to 'estuarine' conditions when rivers are in flood and carry freshwater, nutrients and sediments some distance offshore. Coral reefs support unique and diverse fish and invertebrate communities, and are sensitive to environmental disturbance, particularly increased sediment and nutrient concentrations in the water.

Sandy shoals and beaches

Sandy shoals and beaches are characteristically found near estuary mouths where coastal wave energy is high and there is enough sandy sediment from terrestrial or marine sources. They are much more common in temperate than in tropical Australian estuaries. Sand particles vary from mainly river-derived quartz grains in eastern Australia, to carbonate sands of marine origin in the south and west. Because the size of sediment particles is related to the speed of water movement over the bottom, sandy shoals and beaches are much more dynamic habitats than muddy bottom areas.

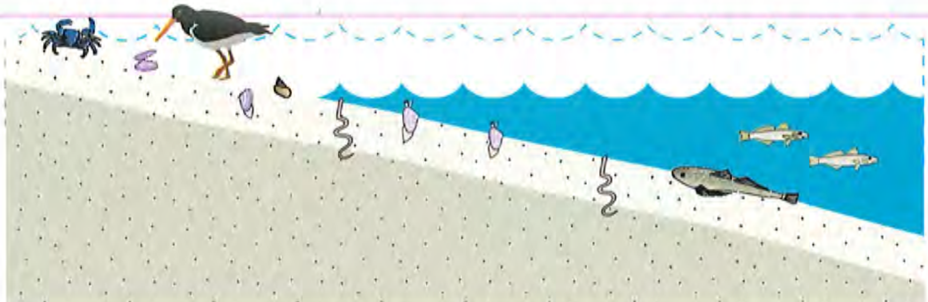
Within sandy areas, particle size varies, affecting the tiny sand-dwelling animals and plants in two main ways. First, larger particles are associated with larger spaces between adjacent particles, which provide habitat for many small species. Second, coarser sediments are also better flushed and oxygenated and animals are able to live deeper than they can in finer sediments.

Sandy shoals and beaches tend to contain fewer invertebrates than mudflats. The species that live in sandy areas are also different from those inhabiting muddy areas. They include microscopic plants on or near the surface of the sediment or migrating between the water-column and the sand, and bacteria and fungi which actively decompose organic material

*Pigface (*Carpobrotus glaucescens*) is common above the tide line on sandy beaches in eastern Australia.*

within the sand. A diverse range of tiny, streamlined animals lives between sand particles. Larger invertebrates, predominantly molluscs, polychaete worms and crustaceans, burrow into the sand. These animals are adapted to an ever-changing environment and can reburrow rapidly following disturbance (e.g. during storms). Extensive intertidal and shallow subtidal sandy shoals are also used by a variety of fishes such as flathead and sand whiting.

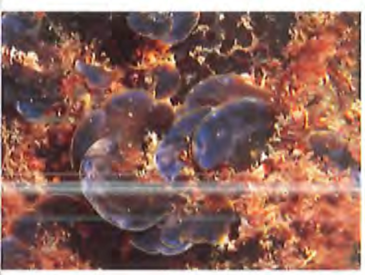
Small sand-balling crabs are active between tides.



A typical fauna of a sandy beach (left)

Rocky shores and reefs

Macroalgae (top to bottom) – Caulerpa sp., Dilophus sp., Lobophora sp., Sargassum sp.

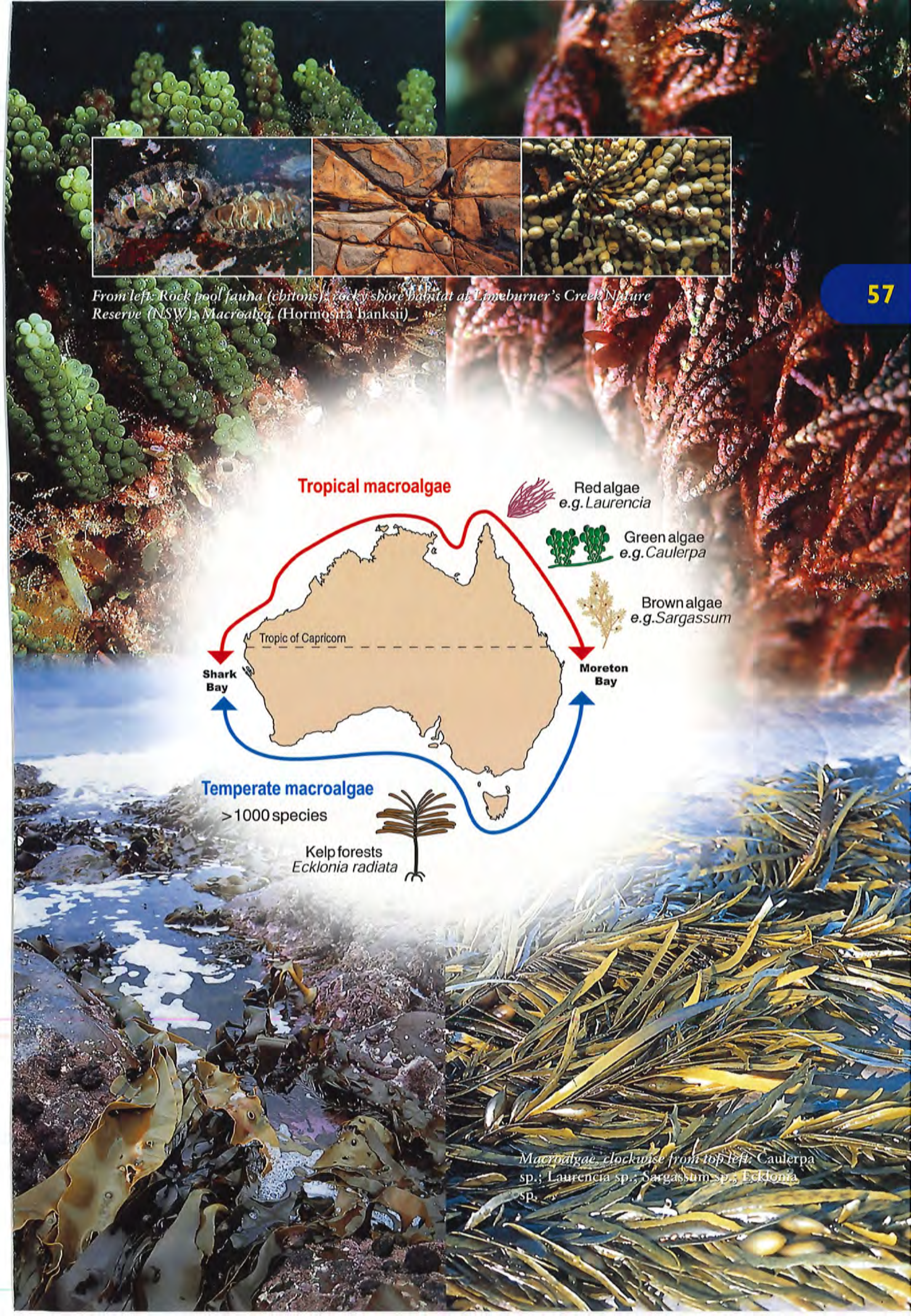


Rocky shores and reefs are common in temperate Australia and occur in association with a number of estuaries, particularly drowned river valleys and embayments. Macroalgae (seaweeds) such as kelps typically colonise subtidal rocky reefs. Unlike mangroves and seagrasses, these plants attach with simple holdfast structures, unsuitable for anchoring in sediments. Macroalgae are dominant in the temperate regions although there are also numerous rocky reef habitats in northern Australia. Well over 1000 species occur along Australia's southern coastline, roughly three times as many as are found in the tropics.

Rocky shores and reefs are habitat for a diverse flora and fauna. Well-lit subtidal and lower intertidal areas are dominated by algae, especially kelps. Where light levels are lower such as beneath kelp canopies, or at greater depths, red algae are more common. Shaded areas are dominated by animals anchored to rocks or other hard surfaces. Examples are sponges, anemones, sea squirts and barnacles. Also common are animals which move about including molluscs, echinoderms (starfish, sea urchins, sea cucumbers), various worms and crustaceans.

The abundance and variety of food and physical diversity of rocky *reefs* enable an abundant and diverse fish fauna to inhabit these areas including larger juveniles of many species. Rocky *shores* are a much less favourable habitat. Exposure at low tide to drying, heat and bright sunlight makes survival difficult. Moving up the shore, algae become smaller, with only encrusting species present at the top of the tide. Many animals have adapted to inhabit rocky shores, such as crabs, predatory and grazing snails, flattened grazing molluscs (limpets, chitons), oysters and barnacles. Various birds feed on exposed rocky shores at low tide.

Typical flora and fauna of rocky shores and reefs (right)

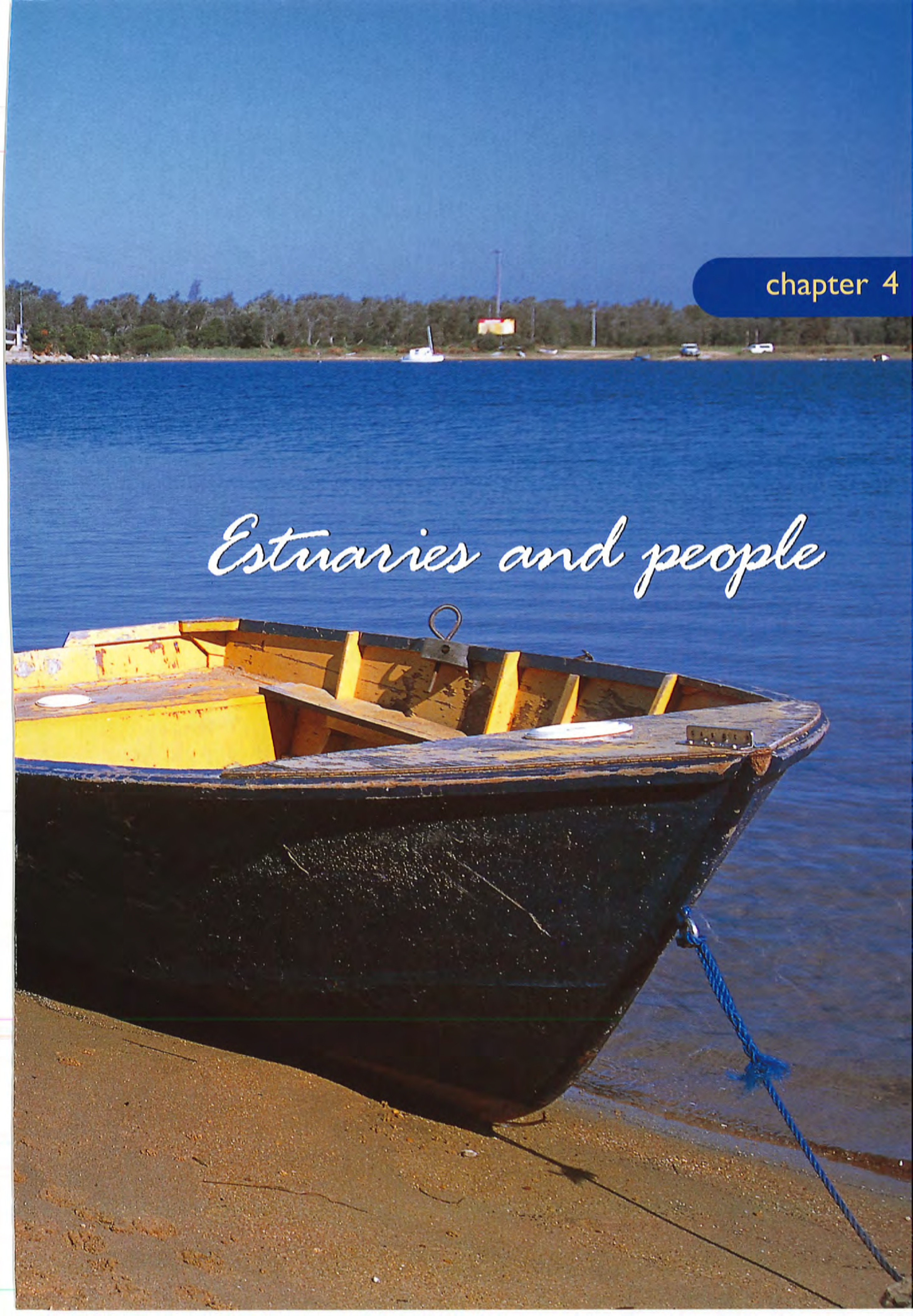


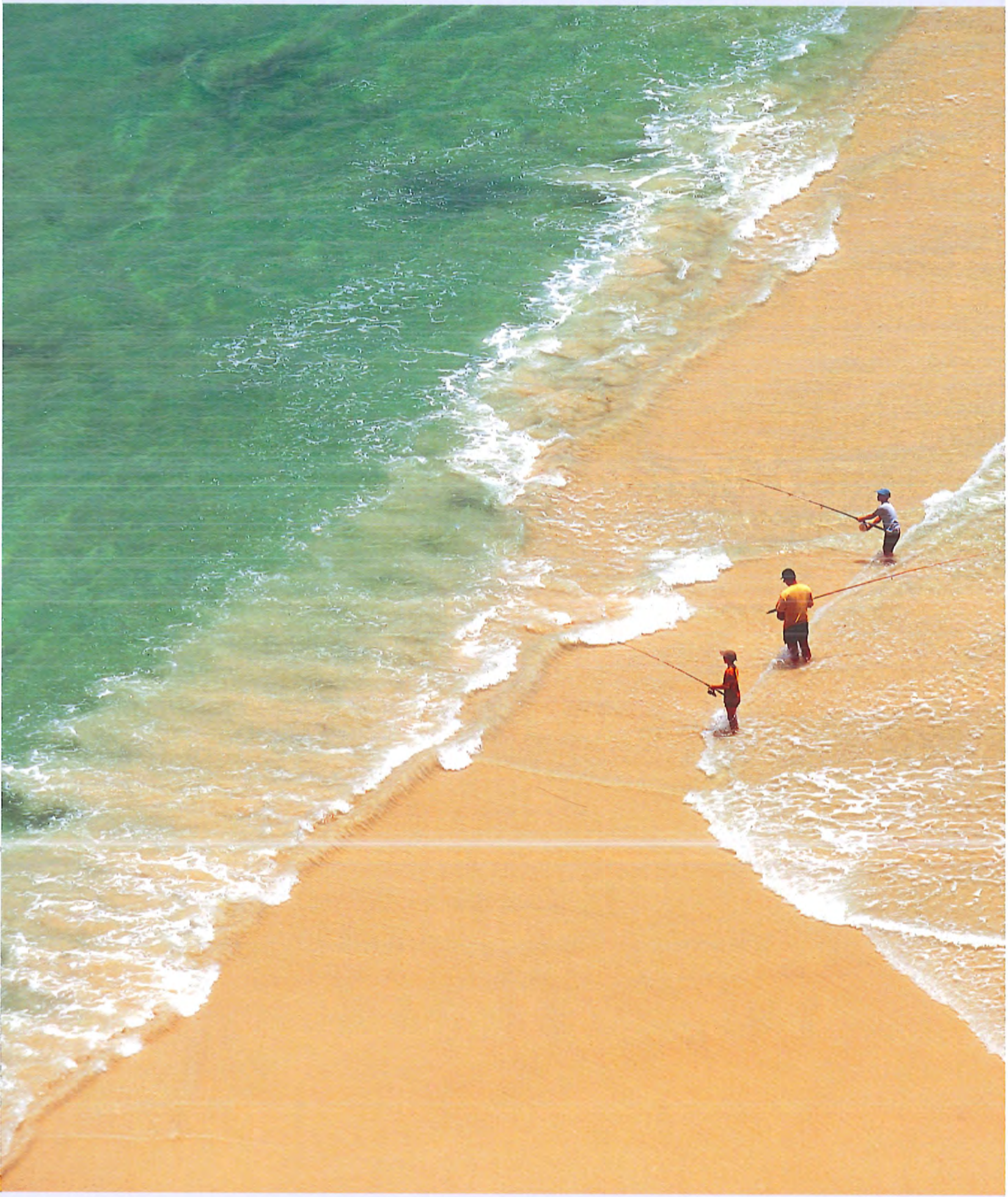
From left: Rock pool fauna (chitons); rocky shore habitat at Limeburner's Creek Nature Reserve (NSW); Macroalga (Hormosira banksii)

Macroalgae, clockwise from top left: Caulerpa sp.; Laurencia sp.; Sargassum sp.; Ecklonia sp.

chapter 4

Estuaries and people





Throughout the world and through history, estuaries have been attractive places for people to live. Resources needed for the human species to survive and thrive are fresh water, reliable and abundant food sources that are easy to harvest, shelter from the elements and fertile soil for agriculture. All are typically found near estuaries.

Productive estuarine ecosystems have long supplied fish, shellfish and many other resources for Indigenous peoples. Sheltered coastal waters have been developed as ports for transport and trade. Urban areas have grown up next to estuaries. Much of the seafood that ends up in modern fish markets is caught in estuaries or depends on productive estuarine spawning, nursery and habitat areas. Estuaries also provide suitable sheltered sites for marine farms as well as boating and other recreation.

These human activities do not occur in isolation from the environment and many estuarine ecosystems have suffered as a result.

This chapter explores how we value estuaries from a human viewpoint. Here we also consider how our use of estuaries has affected the natural environment and how this, in turn, has had a detrimental impact on the very things we value about estuaries. Finally we look at what is being done and can be done to protect estuarine environments. While protecting estuaries is worthwhile in itself, it also protects important natural assets, such as abundant sources of fresh water and food, for future generations of humans.

Fishing at Indian Head, Fraser Island, south-east Queensland

How do we value estuaries?

Healthy estuaries supply many ecosystem goods and services. Ecosystem goods and services are things provided by nature that contribute to the survival and health of people and their societies. These goods and services also contribute, either directly or indirectly, to our economic wellbeing. In assessing indirect economic benefits, we are accounting for the fact that, if ecosystems were not providing these services, we would have to pay to have them supplied in some other way. The alternative is usually very expensive compared with the cost of allowing the natural processes to continue. For example, people need clean water to drink. If this water is taken from a catchment with an intact forest ecosystem, the cost of treatment for human consumption will be much less than the cost of treating water from a catchment that is heavily developed. In this case, the forest is doing us the ecosystem service of providing clean water.

Some examples of the ecosystems services provided by estuaries are given in the table on the following page.

Indigenous use of estuaries

In a land of unpredictable extremes of drought and plenty, estuaries are a relatively stable source of food. Indigenous Australians have relied on the productivity of coastal waterways for tens of

White Ibis feeding on mudflats, Andersons Inlet, Inverloch, Victoria

thousands of years. Prior to contact with European settlers, Aboriginal people had a hunter–gatherer economy. People collected plant foods, shellfish and small animals, hunted large animals and caught fish. By moving among various habitats throughout the year, they were able to take advantage of whatever food source was seasonally available and accessible. Management strategies were used to ensure food sources were reliable and replenished. Traditional fishing practices were refined over time and maintained at subsistence levels through strict adherence to customary laws and traditions.

Ecosystem goods and services	Examples
Wildlife corridors and nursery habitat	Fish and crustacean nurseries and roosts for migratory birds
Buffering capacity	Flood control, drought recovery and refuges from natural and human-induced catastrophic events
Freshwater flows and tidal flushing	Supply of nutrients to the marine environment and removal of pollutants from estuaries
Sediment trapping and shoreline stabilisation	Prevention of soil loss by estuary vegetation, and accumulation of sediment and organic material in riparian habitats
Nutrient supply and cycling	Nutrient supply, nitrogen fixation and nutrient cycling through food webs and breaking down of wastes
Biodiversity	Diversity of genes, species, and ecosystems that ensures continued possibilities both for adaptation, and for future use by people in a changing environment
Fisheries	Food and bait production. Commercial, recreational, Indigenous and cultivated fisheries (aquaculture)
Extractive industries	Sand and gravel extraction
Nature appreciation	Providing access to estuaries and associated wildlife for viewing and walking
Recreation	Swimming, sailing, canoeing, water-skiing, kayaking
Aesthetics and amenity	Residential houses, flats and offices with scenic views
Transport services	Marinas, harbours, ferries and boat ramps
Cultural values	Aesthetic, educational, research, spiritual and intrinsic values of estuary ecosystems

Developing the coastal zone in Port Curtis, Queensland (far right)

Performing a crocodile dance at the Laura Aboriginal Dance Festival (Photo: Robyn Adams)

The relationship of Aboriginal and Torres Strait Islander people to land, water and living resources includes customary rights and responsibilities of Indigenous groups to particular areas, and various restrictions within social groups on the harvesting of resources. Some of these customary rights are now recognised in Australian common law and through native title legislation, which allows for the possibility of native title claims over parts of the sea. Such rights, under the *Native Title Act 1993*, are currently restricted to non-exclusive ownership, and non-commercial hunting and fishing rights according to traditional law.

In a number of areas, mostly in northern Australia, Indigenous fishers are exempt from fisheries regulations when fish are taken by traditional methods. In other areas application of bag limits has led to conflict between managers and Aboriginal people, who have traditionally shared fish amongst large extended families. Indigenous fishing rights remain poorly defined under Australian law, and a number of issues in this area remain unresolved.

Estuaries in European lifestyles

In many coastal areas European settlers have displaced Aboriginal communities and brought a different attitude to resource use. While the Aboriginal economy was subsistence-based, the newcomers introduced different technologies along with concepts of progress, development and profit. The ability of estuaries to perform the ecosystem services for which we value them has often been at odds with the impacts of these technologies and attitudes.

Threats to estuaries

Expanding coastal development

Australian coastal waterways are affected by the concentration of the human population along rivers and estuaries, despite a low population for the land area overall. Most of Australia's major coastal towns and cities have developed adjacent to estuaries and over 80 percent of Australia's population lives in the coastal zone (within 50 km of the coast). During settlement, sheltered estuarine waters were sought out and developed as ports for the movement of people and goods. Rivers were used as highways for transport inland and as sources of fresh water for human use and agriculture. Their fertile alluvial plains grew food for expanding towns and cities. For industry, estuaries were a source of water and a place to discharge wastes. The close proximity of estuaries to ports was convenient for the export of goods.

The ecological consequences of the growth of human population and industrial centres on estuaries have been far reaching. Large areas of habitat are destroyed when wetlands are reclaimed, shipping channels dredged, residential and industrial areas constructed and port infrastructure developed. The ecosystem services provided by this habitat have been lost or compromised by all this human activity.

Stormwater run-off and sewage

When streamside and floodplain vegetation is replaced with impermeable surfaces such as roads and roofs, rainfall can no longer filter into the ground. Instead, when it rains, water runs off into drains and eventually into rivers and estuaries.

Urban stormwater discharge into the Yarra River, Melbourne

Canal development in southeast Queensland

This run-off carries litter and pollutants, such as nutrients, sediment, hydrocarbons, heavy metals, and toxic organic compounds, directly to the estuary via stormwater drains. Sources include car-washing detergents, lawn fertilisers and clippings, animal droppings, motor vehicles, industrial and household waste, exposed soil from road works and subdivisions, pesticides, and oil or chemical spills. Stormwater pollution has consquences for estuarine and marine ecosystems. It can also lead to beach closures after heavy rain.

Ducks and litter on the Yarra, Victoria

Point source discharges are regulated more strictly now than in the past

Rubbish tips are found close to coastal cities and towns. Here rainfall can leach toxic chemicals from contaminated soil. If these chemicals are not contained within the site, they may poison wetland areas or contaminate groundwater.

Bulwer Island, Brisbane River mouth, Queensland

Estuaries are also used to carry licensed discharge of urban and industrial wastes including treated sewage. Increases in nitrogen and phosphorus levels from stormwater run-off and sewage can cause problems such as toxic algal blooms and fish kills in estuarine and marine waters.

Industrial discharges

Many industries are located near estuaries, including smelters, refineries, pulp mills, power stations, abattoirs and factories of various kinds. Several industries, freely discharging waste, have been responsible for some of the worst estuarine pollution in Australia and in some cases environmental problems due to past practices are likely to linger for decades.

Organic matter discharged into estuaries (e.g. from pulp mills, abattoirs or sewage) is decomposed by bacteria depleting oxygen in the water. This can kill fish and other organisms. Pathogens from sewage and poisons such as heavy metals can accumulate in the tissues of shellfish making them unfit for consumption.

Point source discharges are regulated more strictly now than in the past. Environmental risk assessments have become standard practice and ports and industries have put in place measures to reduce their environmental impacts.

Dredge and fill

Another threat to estuarine ecosystems and the services they provide comes from our attempts to physically remodel estuaries for various purposes. Coastal waterways are dredged to maintain navigability and mitigate floods. Natural resources such as sand and gravel, extracted by dredging are put to various uses.

On the other hand, parts of estuaries may be filled to 'reclaim' land for development or to 'train' water movement into channels of our choosing. However, the natural processes which move sand and mud around in estuarine environments are complex. Artificial movement of sediments through dredging and filling can have negative impacts on estuarine ecosystems and sometimes unintended and surprising impacts on valuable coastal assets such as beaches.

Maritime trade and commerce

The manufactured goods and primary products that feed our modern economy move into and out of the country through ports near the major cities and more isolated mining and agricultural centres. The annual revenue from these ports is estimated to be nearly $500 million per annum. Globalisation of the world economy has brought about huge increases in the movement of goods, with world seaborne trade reaching a record high of 5.32 billion tonnes in 1999. However, as recognition and concern for the environment has increased, public pressure and environmental law-making have improved corporate environmental practice.

Port facilities and shipping have polluted estuaries with oil and chemical spills, caused toxic anti-fouling chemicals such as tributyltin (TBT) to accumulate, disturbed estuary fauna and introduced pests. These animal and plant pests frequently outcompete native species and some are voracious predators that threaten native and cultured shellfish and other creatures.

To maintain ports in a navigable state, estuaries have often been dredged and 'trained' with negative consequences on natural ecosystems and their fauna and flora.

Canal development, southeast Queensland

Maritime commerce at Port Curtis, central Queensland

Catchment degradation: Everyone lives in a catchment

Erosion of fertile topsoil in catchments treatens the livelihood of farmers (below)

Since European settlement, most catchments have been vastly altered (bottom)

A catchment is the area of land which drains to a single waterbody such as a lake, aquifer or estuary. Water that runs off the surface of the land finds its way through networks of tributary streams to estuaries and eventually the ocean. On the way it picks up fertilisers, soil, pesticides, heavy metals, acid run-off, oil, bacteria, salts, decaying organic matter and litter. Most of this ends up in the estuary. However we use the land, whether as somewhere to live, to grow food or raise livestock, to excavate mineral wealth or dump our wastes, we affect the health of our rivers and estuaries. In this way, estuaries are the 'report cards' of catchments.

Since European settlement, most catchments have been vastly altered through clearing for agriculture, forestry and urban development, grazing, mining and flow diversions for irrigation, water supply, flood mitigation and hydroelectricity. Everyone lives in a catchment and everyone affects the water quality in a catchment. Since most Australians live close to the coast, most of us live within catchments that ultimately drain to estuaries. In fact, 86 percent of Australians live in coastal catchments.

Widespread clearing, loss of streamside vegetation, overgrazing and poor cropping practices have degraded land, causing problems within catchments. These include erosion of fertile topsoil and dryland salinity, effects that threaten the livelihoods of farmers. At the same time, many land uses transfer problems downstream to rivers and estuaries. Sedimentation, eutrophication, pesticide residues and algal blooms threaten the livelihoods of commercial fishers and other estuary users.

Problems caused by poor land use are compounded by the fact that our social and political boundaries often bear little resemblance to the natural catchment boundaries on which they are superimposed. Council and catchment boundaries do not correspond. This has led to management decisions being made on scales inappropriate to the natural systems they affect.

Land clearance

When land is cleared, habitat is destroyed. The survival of native animals is at risk as the surroundings that provide their particular needs for food, shelter, breeding and protection from predators disappear.

Furthermore, native trees, scrub and deep-rooted grasses bind the soil, slow the pace of run-off and take up most of the water that falls as rain. Once cleared, more water flows off the land. This erodes soil and alters natural wetlands.

Pasture grasses introduced to replace native vegetation are less effective in reducing run-off. Hard-hoofed stock such as sheep and cattle compact soil particles, further reducing the infiltration of water. When heavy rain falls on steep slopes and river banks, fast-flowing run-off cuts into exposed soil. Sediments are then transported downstream to estuaries where they can smother valuable seagrass beds and mangroves.

The widespread removal of trees has also raised the water-table and caused dryland salinity throughout parts of Australia, including areas in the coastal hinterland. Trees pump water from the water-table and without them the water-table rises, bringing with it salt. This salt poisons the soil, reducing pasture productivity and, in severe cases, leaving soil unproductive.

Agricultural run-off

When catchments are cleared, water striking the land surface tends to run off rather than infiltrating the soil surface. Soil exposed through tilling for crops or grazing of cattle and sheep, is eroded by flowing water and carried to rivers and estuaries. Fertilisers rich in nitrates and phosphates, applied to improve productivity on farms, raise nutrient levels in the creeks and rivers that flow to estuaries. Similarly, burning and grazing can increase organic matter and nutrient supply to estuaries.

Gully and bank erosion, Snowy River

The majority of pollution that is funnelled to estuaries from the catchment is delivered in 'pulses' during floods. Here it can cause wide-ranging problems. Soil washed from farmland can cause sedimentation and loss or degradation of estuarine habitats, including extensive dieback of seagrass beds. Increased nutrient concentrations can cause eutrophication and blooms of nuisance algae. Declining water quality affects some species more than others, leading to changes in estuarine food webs and declines in some fish populations.

Herbicides are often used to control weeds such as thistles or capeweed on dairy farms and grazing properties. Rain washes traces of these toxic chemicals down creeks and rivers and into the sea, bays and inlets, where they can be harmful to fish, shellfish and other animals higher up the food chain, including humans. These poisons may cause mangroves and saltmarshes protecting the shore from coastal erosion to dieback.

Agricultural development and tree clearing adjacent to Great Sandy Strait, Queensland

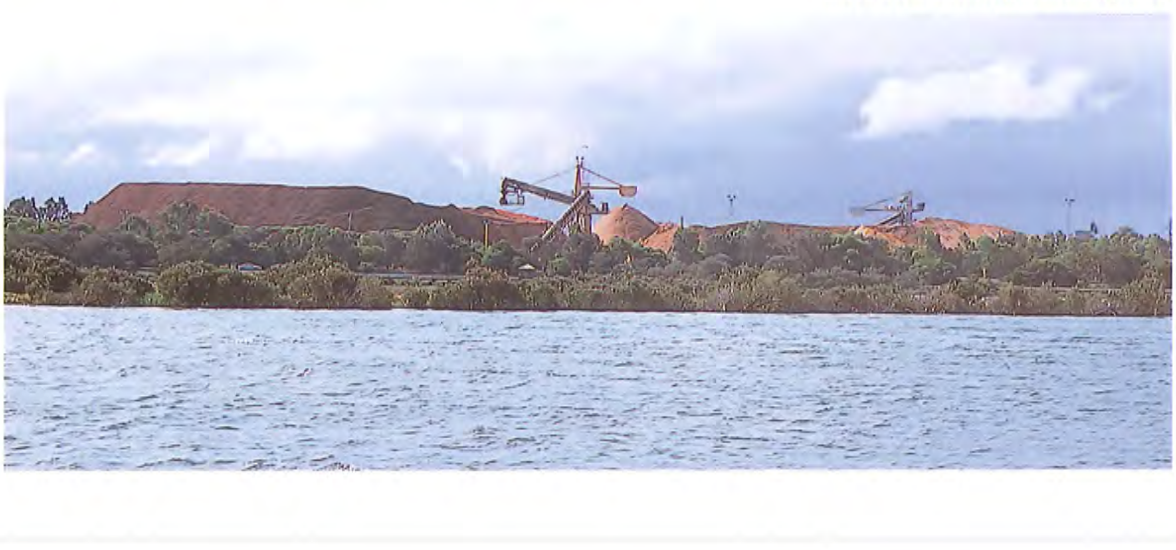
Wetland/floodplain reclamation

Along the coast, many wetlands have been reclaimed for agricultural land by cutting deep channels to drain the water. Wetland plants and animals are displaced as marshy areas are converted to paddocks of pasture grasses. This practice destroys wetland ecosystems and their services, whose economic value may far outweigh the gain from farming these areas.

Mining/extractive industries

Mining activities can contribute sediments, heavy metals and acid run-off, all of which degrade or destroy estuarine ecosystems.

Extractive industry, Bunbury, W.A.



Altered hydrology: To the last drop

Freshwater flows and tides are altered when rivers are dammed or barrages built across estuaries for urban water supplies. Natural flows are also reduced if water is extracted for irrigation and other purposes, sometimes leaving insufficient water downstream to support river and estuary ecosystems and the services they provide.

Developments in the lower reaches of estuaries such as harbours, training walls, marinas and canal estates also affect the natural flows of estuaries. Navigational and extractive dredging can damage seafloor habitat, create plumes of mud and sediment. They can also change estuary circulation patterns. These alterations to the salinity and tidal characteristics of estuaries can contribute to loss or degradation of intertidal habitats.

Changes to natural flow patterns

Freshwater flows, particularly during flood events, supply nutrients and organic material that naturally revitalise floodplain wetlands. Flow-regulating structures such as dams and barrages interfere with this vital process. These structures can also affect signals for breeding or migration in estuarine fishes and physically prevent the migration of fish upstream. On the other hand, water released downstream from large impoundments can be detrimental to animals and plants downstream as it is often cold and low in oxygen. It can also contain toxic compounds such as hydrogen sulfide.

Groundwater depletion

Rain infiltrating surface soil may be drawn up by plants. Otherwise it continues to filter through the soil, topping up aquifers (underground supplies). People sometimes draw on this water for agricultural and domestic use. Groundwater is also part of the natural environment. When it is depleted, either because too much is drawn off or because compacted bare earth prevents water from penetrating, there are consequences for aquatic ecosystems. For example, if groundwater levels are low, estuarine wetlands will be altered. Low water levels in coastal lakes and lagoons may also decrease the frequency of bar-opening, again with consequences to the natural environment.

Sediment trapping

Wetland vegetation slows water flowing towards the sea causing river sediments to deposit. It also physically traps sediment with roots and other structures. So intact wetlands retain nutrient rich sediment and stop it moving further down the estuary where negative impacts such as smothering seagrass can occur. Altering or destroying wetlands interferes with this beneficial sediment trapping.

Beneficial flooding

While flooding can bring inconvenience and sometimes disaster to coastal settlements on river floodplains, natural ecosystems are attuned to these 'episodic events'. Flooding brings nutrient-rich soil into ecosystems and some fish species need floods in order to breed.

Barrage fish ladder, Fitzroy Estuary, central Queensland

Fisheries and aquaculture: Seafood buffet

Oyster racks, Yamba (below)

Fresh prawns for sale at Gippsland Lakes (bottom)

For coast-dwelling Australians, eating seafood is a deeply ingrained part of the lifestyle. In fact, seafood is the only wild-caught food regularly enjoyed by the majority of Australians. Our seafood industry is the fourth most valuable food-based primary industry in the country after beef, wheat and milk. Increasing demand for seafood to satisfy domestic and export markets brings with it increased pressure on fisheries. Estuaries are very important to commercial, recreational and Indigenous fisheries because of their high productivity and because they provide nursery areas and habitat for fish species caught in fresh, estuarine and marine waters.

Estuaries are also important sites for aquaculture. Pens, cages and oyster racks require sheltered areas. Coastal ponds must be close to intake and discharge sites. However, aquaculture can have adverse impacts on estuarine water quality if not properly managed. Increasing demand, on this renewable but limited resource, threatens the long-term sustainability of wild fisheries whose stocks breed in estuarine waters.

Recreational fishing is also a central part of the outdoor lifestyle for many Australians. With more and more people fishing popular spots, catches of many targeted species are falling. The number of untouched areas is rapidly dwindling, while the numbers of fishers continue to increase. As the pressure increases on fisheries from all sides, conflicts arise between different groups with direct interests in fisheries (recreational, commercial and Indigenous) and, as a result, resource sharing in fisheries is becoming an increasingly important issue.

Overfishing

It is now well documented that many of the world's fisheries are exploited at close to, or above, sustainable levels. In many cases when fisheries have ceased to be economically viable, commercial fishers have simply moved to other species. As well, new technology has enabled fishers to more fully exploit existing stocks.

While Australia's record in fisheries management is comparatively good, there is much room for improvement. Current efforts aim to ensure the sustainability of *all* our commercial fisheries.

Recreational fishing is often seen as harmless, but it can have considerable impacts if poorly managed. Recreational fishing is very selective about which fish are targeted. Certain species are more heavily affected, especially top carnivores such as barramundi. In some cases, the size of the recreational catch is greater than the commercial catch. For instance, anglers catch more flathead and whiting than commercial fishers. Bait digging on a large scale can also damage sensitive areas such as seagrass beds.

Bycatch

One of the most intractable problems for commercial fishing is bycatch, that is, unwanted species that are caught in nets. This is a particular challenge for trawlers operating in some of the larger estuaries in northern Australia. Gillnets, which are commonly used in estuaries, can also result in death or injury of bycatch species, particularly if not checked regularly. Use of fine mesh nets can also result in indiscriminate netting of juvenile and non-target species.

Aquaculture

Large-scale aquaculture of Australian marine flora and fauna may bring many benefits, for example, it may alleviate fisheries pressure on wild populations. However, aquaculture also brings environmental liabilities that could prove challenging. Aquaculture ponds and open cages may discharge nutrient-rich wastes, including uneaten feed, faecal waste and chemicals. Caged finfish farming can cause localised organic loading of sediments below the cages, leading to oxygen depletion. Aquaculture can lead to increased incidence of disease in wild populations and to the introduction of exotic species through escapes. Finally, where aquaculture relies on wild-caught stock, there is a risk of depleting wild populations.

Aquaculture on an estuarine floodplain

Recreation and tourism: Sun, sand and surf

Family relaxation in a quiet estaurine environment, south-east Queensland

Many Australians and overseas visitors choose coastal areas for recreational activities, as holiday destinations or simply to enjoy the outdoor environment. During the long hot summer, millions of people flock to beaches and estuaries to relax and play. Local economies in coastal areas are increasingly geared towards tourism, with recreational opportunities a key drawcard. Local businesses promote boat hire, waterfront cafes and seafood restaurants, estuary cruises, fishing and dive charters, cultural tours, golf, bushwalking, horse riding, joy flights, swimming, local arts and crafts and various tours.

Estuaries are a natural focus for recreation because of their sheltered waters, which provide a haven for swimming, sailing, boating and fishing. Individually, these activities cause only minor impacts, but multiplied by the many thousands of people involved, and combined with their associated developments, recreational activities are contributing to the declining health of many estuaries. Much recreation depends on a healthy ecosystem, without toxic or nuisance algal blooms or pathogen contamination of the water, and with healthy fish stocks for recreational fishers. People want to know they can swim, boat and fish.

According to the Bureau of Tourism Research, 42 percent of domestic tourism and 50 percent of international tourism is now marine- or coast-based.

Cumulative impacts

Tourism and recreation can have wide-ranging effects on estuarine ecosystems. The effects of relatively low-impact activities, such as camping, swimming, boating and fishing, accumulate and can be quite significant over a number of years. Litter is a problem in many areas – it is unsightly and can entangle or choke native animals. The rapid growth of small towns, particularly when populations boom during holiday season, can overload the capacity of septics and other local wastewater disposal systems. Waterway pollution can result. Foreshore development often replaces ecologically valuable streamside vegetation with concrete or stone walls, roads and fertilised lawns.

Boating impacts

High-density boating activity and marinas can cause water and sediment pollution (nutrients, toxicants, pathogens) from spills, exhausts, untreated sewage and anti-fouling chemicals. In addition, construction of marinas can lead to the physical destruction of foreshore and bottom-dwelling aquatic communities. Wash from boats can erode shorelines, while anchors and propellers can damage sensitive sea-floor habitats. Speedboats can cause disturbances to wildlife such as nesting birds and injury or death to turtles, dugongs and other large animals .

Overcrowding

High levels of access, particularly during holiday seasons, can place a strain on public amenities, leading to foreshore erosion, four-wheel-drive damage to vegetation, high levels of litter, septic overflows, weed introductions and a range of boating impacts.

The desire to live and recreate by the water often leads to coastal wetlands being bulldozed for new resorts, golf courses and marinas. At the heart of this problem lie conflicting social values relating to people's priorities for recreation. People visit estuaries for different reasons and the different ways in which we use them for recreation are not always compatible (e.g. high-speed water craft such as speedboats and jetskis may be hazardous to swimmers). Another problem is that of too many people wanting the same thing, with overcrowding affecting both estuary users and the environment.

Overcrowding and littering can seriously detract from the aesthetic appeal of beaches as well as the ecology (above).

Marinas can contribute to water and sediment pollution through spills, exhausts, untreated sewage and anti-fouling chemicals (left).

Caring for estuaries

Ailsa Buxton – Redbank, Stratford

"Our hope is there will be more water for the river"

Alister and I farm at Redbank on the Avon River inland from Lake Wellington in Gippsland. Our property borders on the estuary floodplain and morass wetlands. I have maintained an active involvement in the Avon Trees Group, the Wellington Salinity Group and also the Gippsland Coastal Board over some years now. I monitor (for eight years now) two sites for Waterwatch in the river at the whereabouts of the Nuntin Creek, a returning site for irrigation waters of the Macalister Irrigation District. We fenced and revegetated the north side river riparian vegetation about 15 years ago with a view to bank stability. Presently a Stream Flow Management Plan for this estuary river is being carried out and my hope is there will be more water for the river from this process.

Ailsa Buxton looking over the Avon River and Lake Wellington Estuary

Col Dyke – Little Swanport Estuary

"Of all the world's ecosystems or biomes, estuaries provide by far the highest value in ecosystem services"

Balancing ecological and socio-economic issues in estuaries and coastal areas comes naturally to Col Dyke and his family, as their aquaculture business depends upon estuarine health and function. Plenty of assistance particularly from wife Suzanne and the rest of the family gives Col the time and resources to address the issues at all levels.

Col's industry leadership in developing hazard analysis, risk assessment, management controls and license conditions for sustainable aquaculture is legendary, as is his initiative (carrying government and the community with him) in developing the Strategy for the Management of Ricegrass in Tasmania's waterways (internationally recognised as 'world's best practice') and his involvement in catchment management planning.

Col says the success of those projects has heralded a change in community attitude. People are proud of their achievements and recognise the need for monitoring and improving waterways.

Col is currently encouraging and promoting the development of environmental management systems for estuaries, with all community sectors involved and working toward friendly and sustainable outcomes.

Col Dyke, 20 years in aquaculture – intertidal shellfish (oyster) farming

Bob Muir – Darumbal Country

"I work with everyone and anybody to look after country"

My name is Bob Muir. I am Woppabura from the Keppel Islands which is part of the Darumbal's Nation.

Darumbal country extends from the mouth of the Fitzroy River south, to the Styx River north and the Great Barrier Reef east, to the base of Mt Morgan Ranges west. Traditionally, it is my responsibility to look after country and that means I have to work with everyone and anybody to look after country.

Bob Muir, Red Beach Keppel Island, 2004

Col Creighton – Clarence River

"...building corrugated iron catamarans, catching prawns, jewfish and mudcrabs were all skills I learnt at an early age..."

Colin Creighton grew up on Palmers Island, beside the Clarence River and sometimes, during flood, in the river. Exploring estuaries, building corrugated iron catamarans, catching prawns, jewfish and mudcrabs were skills learnt at an early age, often instead of school.

Returning to the Clarence following a few years in heavy industry and mining Colin deckhanded for Jim Bultitude on the prawn trawler *Seadreamer*. Long talks between shots led to an agreed philosophy – you cannot stop development, but you can direct it. Colin has been working to that philosophy ever since.

Some of his big fishy involvements include stopping and then starting reversal of wetland drainage in northern NSW floodplains, a voluntary dieldren ban in NSW cane areas before Australia banned it, the first catchment committee in NSW on the Clarence, Lake Innes Nature Reserve, Elizabeth–Middleton Reef National Nature Reserve, Commonwealth section of Ningaloo Marine Park and various fish habitat reserves, improved management in NSW and north Queensland, including the Gulf and Torres Strait.

Colin left the pleasures of working in north Queensland to lead the small team coordinating the *National Land and Water Resources Audit* – developing awareness of Australia's natural resources and building the bridges between science and natural resource management.

Col Creighton, showing some values of estuaries to the next generation

Caring for estuaries

Joy Davison-Lee – Ross Creek, Yeppoon

"Estuaries are teeming with life and a sanctuary for many"

As a flying fox carer I find it an enthralling experience to visit the Ross Creek colony to see the bats hanging from branches like bundles of black fruit. Towards dusk the animals become active and the air gradually fills with noise. At dusk the bats fly off in search of food. At such times the sky becomes filled with huge forms – noiseless and awe-inspiring.

It might seem remarkable that flying foxes should frequent mangrove estuaries where there is no suitable food. However, one of the many functions of the mangroves is to provide a sanctuary for flying animals which range widely for food then retreat into the safety of these areas. Few enemies can penetrate easily along the ground into such places and mangroves act almost as islands in terms of safety.

Joy Davison-Lee cares for injured flying foxes.

Claudine and Gary Ward – Karumba

"We take pride in being part of a proactive group..."

Gary and Claudine Ward, fishing the Gulf for over 25 years

Gary and I have been fishing the Gulf waters for over 25 years. During that time we have been part of a group ensuring that Gulf fishermen become an organisation of people who care for, and strive to maintain, an ecologically sustainable industry in the region.

Our association – The Gulf of Carpentaria Commercial Fishermen Incorporated – has developed a code of conduct and environmental management plan that we hope will lead the way for the future of our industry in the rivers and waters of the Gulf of Carpentaria. We also instigated the legislation of a dugong-sensitive zone in the Wellesley Islands. We take pride in being a proactive group and maintain a close association with biologists from the Department of Primary Industries, economists and local catchment management groups.

Barry Phillips – Gippsland Lakes

"I've fished and sailed these Lakes for 40 years"

Barry Phillips and Pelican Bay

I have been connected with the Gippsland Lakes for 40 years. I am on the local foreshore committee and have been involved over the last few years in the Loch Sport Boat Club clubhouse, entirely built and funded by local volunteers. Emphasis now is on sailing activities in my role as coordinator of the club's Australian Youth Federation Sailing Program. I monitor three estuarine sites for Waterwatch and also report dolphin sightings to the Dolphin Institute in Melbourne. Dolphins regularly appear here. I recently spent two hours sailing with a pod of some 30 to 40. I enjoy competitive sailing, fishing and cruising.

Bernie Stone – Eprapah Ck, Moreton Bay

"Estuaries are there to be kept clean and blue!"

Bernie (Bernard) Stone's first encounter with the Eprapah Creek Estuary (1946) as a Scout leader on a Wood Badge course led later to being a Sea Scout leader (1956–1961) and then training Venturer Scouts in testing estuarine water quality (1973–1991). As Eprapah Creek Catchment and Landcare Association project leader (1990–present) this obsession with saltwater continues as does his leadership role in transitional zone riparian revegetation, estuarine water quality audits and collaborative wetlands events (Banrock Station Wetlands). Any achievements as a volunteer coastal waterwatcher (30 years) have been strongly supported by many others including Scouting folk, particularly by Anne Stone (wife and environmentalist *par excellence* in her own right) and in recent years by Lynn Roberts (ECCLA WaterWatch/CoastCare Coordinator).

Bernie Stone demonstrating water testing and training in water ecology in Eprapah Creek Estuary.

Bill Sawynok – Fitzroy Estuary

"Estuaries are like arteries in the body – the flow in them sustains life!"

Estuaries, with their ever-changing moods brought about by the daily ebb and flow of the tides, have provided me with fishing challenges for the past 30 years. I am fortunate enough to live where catching barramundi is part of the everyday reality of fishing, something that many people only dream about.

My love affair with barramundi spawned a desire to understand the fish and estuaries better. That started out almost 20 years ago with tagging fish to obtain information on their growth and movement and has graduated to learning how they use different parts of the estuary at different stages of their lives.

Bill Sawynok with a Fitzroy barra

Dealing with human impacts – integrated management strategies

Previously we have seen how human activity in catchments and on the coast can degrade estuary ecosystems. Increasingly we recognise that the problems of degrading natural resources on our coasts must be tackled in the framework of the *total* system within which they occur. Attempting to deal with issues in isolation (for example engineering responses to estuary eutrophication) have often proved unsuccessful, simply diverting the problems elsewhere or even being counter-productive. Integrated management considers people in ecosystem processes. Such management identifies the physical and ecological links between natural systems and those dominated by human economic activity. Coast and catchment communities must be involved in management. Community members must become more aware of the need for conservation of natural resources.

An integrated approach helps identify and tackle the causes of estuarine degradation. Integrated catchment management or total catchment management initiatives, within government and community natural resource management programs, are examples of such an integrated approach. These initiatives emphasise the importance of considering all resource needs and all environmental effects within a catchment when planning any development. An integrated framework requires land use to be planned on a whole-of-catchment as well as a local scale, including the distribution of protected areas. Because catchment, coastal zone and marine areas are continuous, our representative networks of protected areas must be chosen to support the continuity of processes linking these areas.

Issues to actions

Urban, industrial and port development

Urban estuaries have been irrevocably transformed by human activities. While it is not feasible to restore these estuaries to their original condition, it is important to halt their further decline and to re-establish a healthy and dynamic ecological state. In recent years, we have seen a change towards a society that celebrates its urban estuaries and no longer accepts their use as mere repositories for our wastes.

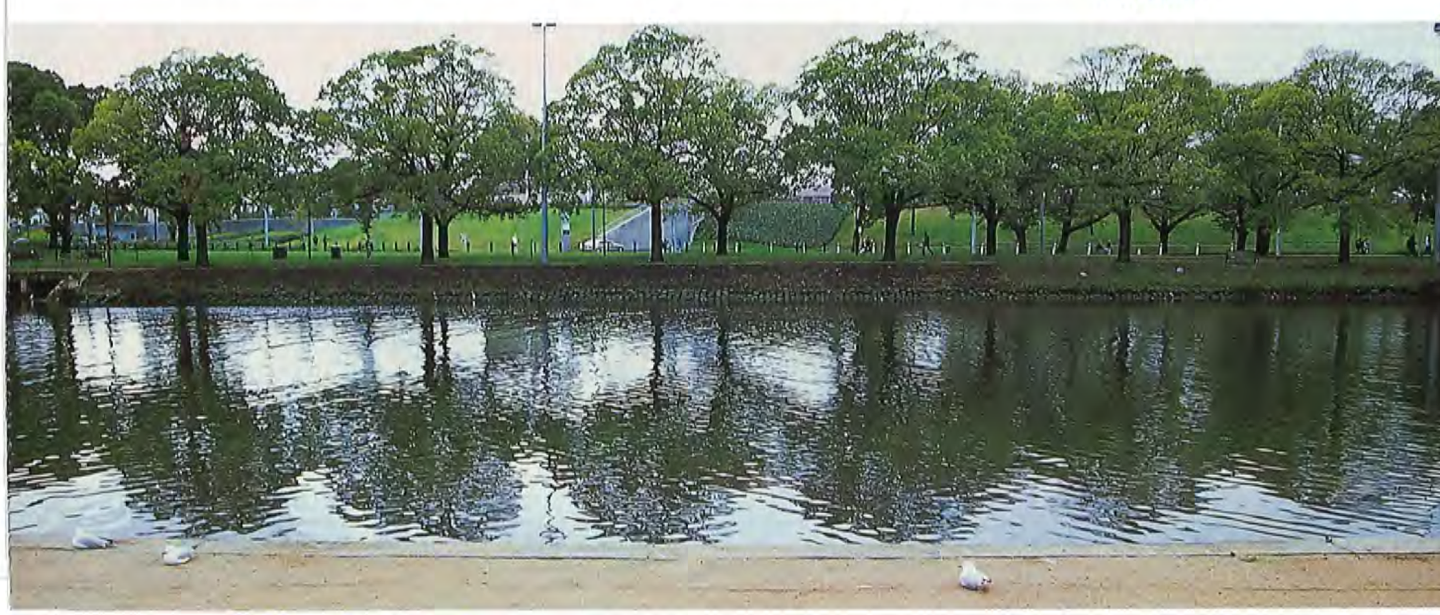
From back door to front door

There is a tremendous amount of work to be done to reverse current trends and restore healthy ecological processes in our urban estuaries. If we are to succeed, the most important change is a change in how we view our estuaries. We must stop thinking of estuaries as the 'back door' to our cities and start seeing them as the 'front door'. Urban renewal projects can help highlight the plight of our estuaries and stir public interest in change. Reclaiming foreshore by replacing old warehouses and factories with public parkland and improving access to wetland areas (e.g. mangrove boardwalks) draws people to use the estuary and encourages a sense of public ownership and responsibility. This change in attitude is manifested in campaigns to tackle the problems of pollution and litter (e.g. *Healthy Waterways*, *Clean Up Australia*) and public celebrations of our estuaries as defining features of our cities (e.g. Brisbane's *RiverFestival*).

Public education is vital for shifting attitudes. This can take many forms – music and art, information packages for schools or better signs and information to highlight the ecological values of our surviving urban wetlands. Because of the extent of habitat loss in urban areas, virtually all the remaining, relatively intact, riparian

Interpretive signs inform people about their local waterways and encourage them to take an interest

Yarra River, Melbourne



From top: green prawn from southeast Queensland waters;

closures at critical breeding times can help protect fish stocks;

litter trap on the Yarra River, Melbourne

and wetland areas have acquired high conservation significance. They should be preserved as habitat and refuge areas.

Technology can us help tackle the causes of declining estuarine health. Technological solutions include sewage treatment upgrades, wastewater reuse schemes and changes to stormwater management. Modern sewage treatment techniques can greatly reduce the human health risks and environmental impacts of sewage discharge. Almost all of the bacteria and viruses, and much of the nutrient present in sewage, can be removed with tertiary treatment techniques such as UV exposure or microfiltration. Wastewater can be diverted from estuaries to be used on certain non-food crops in place of commercial fertilisers.

Stormwater management is also entering a new era. Whereas a traditional stormwater network acted to channel run-off into waterways as quickly as possible, stormwater management devices now reduce peak flows, trap litter and filter pollutants from stormwater. These devices include physical pollutant and litter traps as well as constructed wetlands, which capitalise on the natural filtering capacity of aquatic plants.

Strict licensing of point source discharges has greatly reduced pollution from industry, though there is often considerable room for improvement. A range of actions can also be taken to reduce risks to estuarine health posed by large ports. Navigational dredging and the dumping of dredge spoil should be tightly regulated to minimise impacts. Areas of important habitat within port jurisdictions should be preserved. Every effort should be made to reduce the risk of environmental harm due to accidental spillages and other accidents. Improving management of more intractable problems such as ballast water and toxic anti-fouling treatments must be a priority.

Measuring the ecological footprint

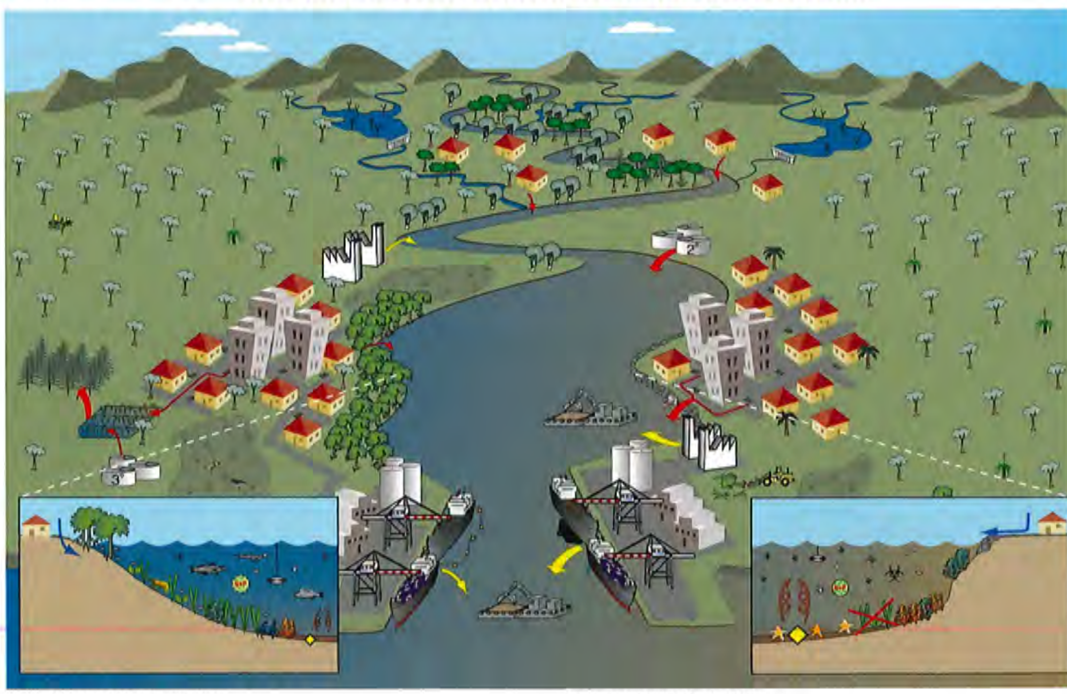
If our efforts to restore degraded estuaries are to be effective, we need research to help us understand what is causing them to decline. This decline often involves many contributing factors that can interact in subtle and unpredictable ways. Successful research requires a source-to- sea approach with input from many disciplines. Research priorities clearly depend on the estuary in question. However, they could include the following – investigations into specific causes of toxic algal blooms and what can be done to prevent these occurences, research into improved constructed wetlands, better ways of treating ballast water and research to develop less toxic anti-fouling treatments for ships.

In urban estuaries, it is important to monitor stormwater loads (of sediments, nutrients, toxicants) and the effectiveness of different stormwater management devices. It is also important to determine how far sewage extends from treatment plant outfalls. This allows us to assess sewage influence on the ecosystem and to document the effectiveness of treatment plant upgrades. Standard water quality measurements, such as nutrient concentrations, dissolved oxygen levels, chlorophyll *a*, turbidity and/or secchi depth, salinity and pH, can be performed on a regular basis. Water and sediments can be screened for toxic substances and monitored regularly.

Natural processes within the estuary are complex, so it can be difficult to relate these physical and chemical characteristics to effects on plants and animals. However, standard water quality monitoring can be complemented with measurements that help us better understand the effects on plants and animals. Examples of natural processes that can be measured include the flows of nutrients within sediments, phytoplankton bioassays, seagrass depth range and macroinvertebrate surveys. Novel monitoring methods, such as *in situ* monitoring and satellite remote sensing, promise a great leap forward in the amount of data that can be gathered. It will be important to establish the aims of such monitoring clearly if these methods are to be used well.

Finally, social, economic and human health indicators must be also developed if people are to be recognised as part of ecosystems rather than separate from them.

Urban, industrial and port development – good and poor practice



Good management practice

- Nutrients and pathogens removed from sewage
- Sewage nutrients utilised eg for irrigation of plantation forestry
- Constructed wetlands treat stormwater and sewage discharges
- Impermeable surfaces minimised to maximise infiltration
- Surviving wetland areas protected
- Areas of natural foreshore retained
- Strict controls on industrial discharges
- Measures taken to minimise pollution risk from port
- Ships' ballast water managed to reduce risk of pest invasion
- Dredge spoil dumped in designated areas

Poor management practice

- Low levels of sewage treatment
- Sewage nutrients and pathogens discharged into estuary
- High proportion of impermeable surfaces leads to high runoff
- Stormwater flows directly to estuary
- Surviving wetlands destroyed
- Heavily modified foreshore
- High levels of industrial discharges
- Toxicants enter estuary from port eg TBT, oil spills
- Pest organisms enter estuary from ballast and hull fouling
- Dredging occurs within estuary

Catchment land use

Many of our coastal catchments are badly degraded and, as a result, are responsible for much of the sediment and nutrient pollution in estuaries. While it is straightforward to identify general causes of declining water quality, tracing diffuse pollution to its various sources is more difficult. Because of the extent of catchment degradation, the key challenges in the short-to-medium term are to prevent further declines in catchment condition and prioritise restoration activities to make the most of limited resources.

Shady streams and vegetated catchments

Improving the health of our estuaries will ultimately take a whole-of-catchment approach. This is recognised in the advent of integrated and total catchment management (ICM and TCM) initiatives. However, because natural catchment boundaries rarely correspond to legal boundaries, these programs face enormous practical hurdles.

At present, competition between management groups for limited resources often discourages the sort of communication and cooperation needed to solve catchment-scale environmental problems. Many landholders also resent what they view as an imposition on their right to do as they please on private land. Involving the community in land management is a first step towards tackling this problem but successfully changing current practices will need more than an appeal to conscience. The cost of reversing land degradation is often prohibitive for landholders. Appropriate incentives for improved land management are needed in conjunction with legal restrictions (e.g. restrictions on land clearing). Education to increase community awareness of the need for better management of natural resources is also essential.

Volunteers revegetating a catchment (below)

In practical terms, much can be done to reduce the transport of soil, nutrients and other contaminants to waterways. Better planting and harvesting practices, involving a minimum of soil disturbance, can reduce soil loss from cropland. Natural riparian areas should be maintained or restored to reduce rates of streambank erosion and to slow run-off, allowing silt and nutrients to settle out. Channels and ponds planted with grasses, reeds or other plants can be used as effective sediment and nutrient traps.

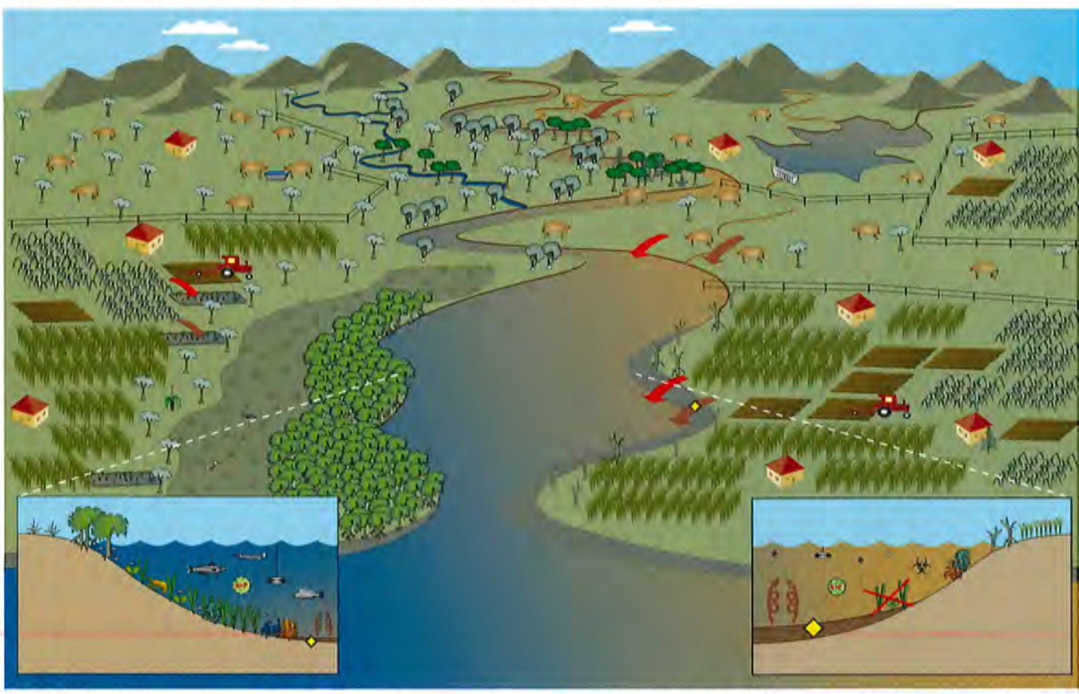
Reducing stock access to streams is important to reduce streambank erosion. Where hillslope erosion is identified as primarily responsible for sediments deposited in an estuary, improvements can be made to land cover, stock access and density. In marginal lands, environmental costs may outweigh the economic benefits of running stock at very low densities. In such cases, destocking must be an option. Improving the efficiency of water use in the catchment (e.g. using drip irrigation) has benefits that flow all the way to the estuary.

Where does it come from, where does it go, what does it do there?

Where do we start to rehabilitate a degraded catchment? Given limited resources, the challenge is to achieve maximum gains in estuarine water quality. For this reason a thorough catchment survey is important to determine land use patterns, identify current and historical sources of pollution and identify water users and diversions. Rates of erosion and nutrient loss vary markedly throughout the catchment, according to rainfall, soil type, relief, the extent of vegetative cover, the condition of riparian vegetation, land use and other factors. Comparing isotope markers in catchment soils and estuarine sediments can identify areas within the catchment that contribute significant amounts of sediment to the estuary.

Continued research into improved, cost-effective methods of landscape rehabilitation is essential. As well, research is needed to measure the quality of water flowing to the estuary and the sources of pollution within the catchment. It is also important to identify the specific pollutants of concern. While sediments and nutrients can be a problem almost everywhere, local threats may include acid run-off and metals from mine tailings, acid sulfate soils, pesticides or pathogens. Positioning monitoring stations above and below places where streams meet is important to identify the sub-catchments of greatest concern. Because most Australian catchments deliver most of their pollutants to estuaries during a few short run-off events after heavy rainfall, it is important to start monitoring as soon as possible after these events. *In situ* water quality monitoring has good potential for helping us track this variability in pollutant delivery over time.

Catchment land use – good and poor practice



Good management practice

- Better farm practices reduce erosion and nutrient runoff
- Stock fenced off from creeks & remote watering points provided
- Sustainable drainage networks around farms
- Riparian buffer strips preserved along creeks
- Wetland areas protected
- Filter strips and artificial wetlands reduce silt/nutrients in runoff
- Riparian vegetation promotes infiltration of runoff
- Efficient irrigation practice reduces water use
- Base flow from groundwater to streams maintained
- Appropriate use of pesticides

Poor management practice

- High levels of sediments and nutrients in agricultural runoff
- Sediments and adsorbed nutrients flow to estuary
- Nutrients in groundwater enter catchment streams
- Stock in creeks cause erosion of streambanks
- Riparian vegetation cleared or badly degraded
- Compaction and sealing of cleared soil surfaces
- Wetland areas reclaimed for agriculture
- Impoundment and extraction reduces base flow in streams
- Faecal bacteria from stock in waterways
- Overuse of pesticides and poor application practices

Fisheries and aquaculture

Estuarine fisheries provide many benefits for the Australian community. However, many of these fisheries are under increasing pressure from all sectors of the fishing industry. Resolving resource-sharing conflicts and ensuring the long-term sustainability of fisheries, as well as protecting estuary biodiversity, will bring changes to many current practices. Research and monitoring are needed to establish and refine what limits to fisheries are needed for long-term sustainability.

Fish for today, fish for tomorrow

Ecologically sustainable fisheries management allows present needs to be met without compromising the ability of future generations to meet their needs. Regulations limiting commercial licences and establishing seasonal or permanent closures, fish reserves and bag and size limits are important. These restrictions reduce capture of undersized and oversized individuals, so fish and crustaceans can reproduce.

Ecologically sustainable fisheries leave productive seagrass beds intact.

Reserves protect fish and their habitat, an important component of fisheries management. A representative system of protected areas over a range of estuarine environments, some excluding collecting and fishing, would help conserve bio-diversity. Protected areas are also important as scientific reference and monitoring sites. A zoning system with a range of impact levels, such as that used by the Great Barrier Reef Marine Park Authority, can balance fisheries and conservation objectives.

Some fishing equipment is restricted or prohibited, as is the taking of certain species. Use of certain equipment and methods can reduce the impact of fishing on estuarine habitats and non-target species. Bycatch-reduction devices and turtle-excluder devices are being trialled in Queensland to address the problem of trawler bycatch. Damage to benthic habitats can be reduced by designing trawl nets raised from the sea floor. Varying mesh sizes of nets and gaps in crab pots helps avoid netting juvenile and non-target species. Regular net checks can reduce bycatch deaths. Recreational fishers can also do their bit by removing tangled fishing lines and using biodegradable cornstarch bait bags instead of plastic ones.

Wise management of aquaculture projects would minimise habitat loss and disruption to ecosystems. Coastal ponds built above high tide, outside wetland areas would not alter local hydrology or disturb acid sulfate soils. Disturbance to estuary vegetation should be minimised and limits placed on contaminant levels in discharge. The effects of nutrient loads from caged fish-farming must be considered at an estuary-wide scale, with local effects of individual farms taken into account and stocking rates managed accordingly. Exotic species must be securely confined and managed to ensure feral populations do not establish in estuarine or coastal waters.

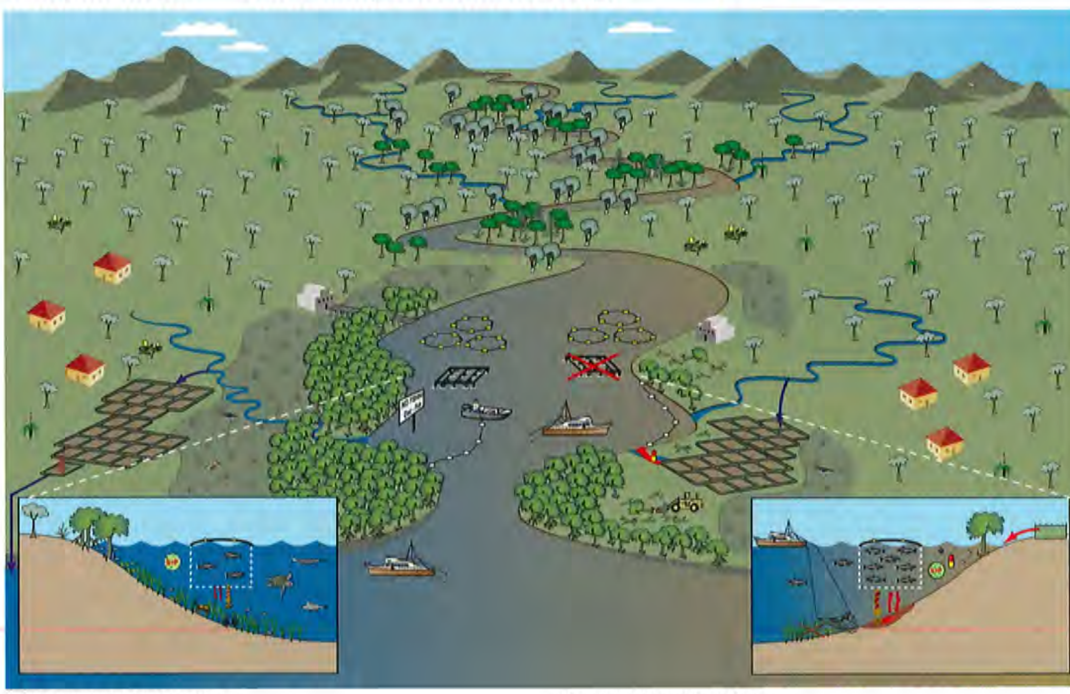
How much is enough?

Research and monitoring are basic to evolving fisheries management. Sustainable fisheries need managers with a good understanding of fish biology, population structures and health, interactions between fish and their ecosystems and the effects of fishing and other activities on populations and habitat. While we have good information for some species and some places, there is much to know about Australia's fisheries to ensure their long-term survival. Research into fish biology (e.g. growth rates, life history, population structures,genetics) provides critical information on how much can be sustainably harvested. It also helps us understand fish life stages and populations most at risk from fishing and other activities. Other examples of priority research are: more detailed investigations of how fish interact with different habitats, the use of stocking techniques to rehabilitate or enhance fisheries, research into effects of pollution such as acid sulfate run-off on fisheries and the relationships between aquaculture and wild fisheries.

Monitoring gives vital feedback on the success or otherwise of fisheries management. Information recorded from commercial fishing provides data about catches in relation to effort, the types of species caught, size distribution and fish movements or migrations. However, use of catch data can overestimate wild populations. Surveys using scientific sampling techniques produce more accurate information on fish population size and changes. Biological sampling of such survey catches gives extra information on size and age distribution, sex ratios, spawning condition and diet.

Aquaculture research must be designed to give understanding of how to reduce environmental impacts. Examples are developing better feeds and feeding efficiency, reducing potential for disease transfer or genetic contamination of wild fish stocks, finding better ways to treat waste and producing farmed rather than wild-caught larvae. Monitoring of discharges, water and sediment quality are vital to see aquaculture development impacts and ensure compliance with licensing.

Commercial fishing and aquaculture – good and poor practice



Good management practice

- No trawling in sensitive estuarine habitats
- Use of alternative, more selective fishing methods
- Seasonal closures for protection of spawning stock
- Responsible capture and release of bycatch
- Prawn farms developed outside wetland areas
- Prawn farm tailwater discharged to site with good tidal flushing
- High quality feed used and regular fallowing of cage sites
- Sustainable use of wild larval stock
- Medicated feed a response to specific diagnosis of disease
- Overstocking of ponds and fish cages avoided

Poor management practice

- Indiscriminate trawling in estuary & netting of entire creek mouths
- Fishing during spawning season reduces fish stocks
- Indiscriminate netting of juvenile and non-target species
- Wetlands destroyed for pond and infrastructure construction
- Overfeeding leads to high nutrient levels in pond effluent
- Organic decomposition leads to anoxic areas near fish cages
- Unnecessary use of antibiotics in feed
- Unregulated harvest of wild larvae may impact adult stocks
- Exotic fish species escape from cages
- Poor water quality precludes development of shellfish farms

Facilities such as boardwalks and boat ramps can be constructed to minimise the impact of recreational activities on estuaries

Surfing at Arrawarra Beach, northern New South Wales

Recreation and tourism

Up to a point, recreation and tourism protect social and environmental values. This is because of the incentive to protect what people come to enjoy. However, recreation and tourism are often closely followed by rampant coastal development, which can be an environmentally and culturally destructive influence. Well-managed ecotourism can bring money to local communities without adversely affecting estuarine environmental values.

Water to swim, drink, fish and celebrate

Managing estuaries for recreation and tourism means balancing demands of competing uses that may be incompatible with recreation for aesthetic or health reasons. Limiting impacts of recreation on the estuary is also important. As well, a balance has to be found between various recreational uses and nature appreciation, not all of which are compatible. For example, speedboats or jetskis will spoil an area for swimming or birdwatching.

One approach to managing these conflicting demands is a system where specific uses are permitted in zones, as determined by an estuary management plan. For such a system to work, it is important to raise public awareness through education on the estuarine values that may be threatened by recreational activities, as well as to provide information on human health risks posed to recreation by other estuary uses. Protective management of near-pristine estuaries would usually be compatible with low-impact recreational and ecotourism activities, focussed on appreciating and conserving these ecosystems.

Specific actions to reduce the impacts of recreational activities include limiting vehicle access to foreshores and ensuring public amenities are maintained or improved to cope with increased visitor numbers. In addition, visitor numbers to heavily visited areas or areas of high conservation significance can be limited through the issuing of permits. Bins can be provided and education or penalties can also help reduce litter. Programs to remove litter from foreshore areas both improve amenities for recreational use and reduce the hazards posed by litter to estuarine fauna.

A range of measures can be taken to reduce impacts of recreational boating and marinas. Siting and design of marinas are two important considerations. New marinas should not be constructed in environmentally sensitive areas and should be located and designed to maximise water flushing. Pollution control measures should be implemeted in marinas. Care should be taken in maintaining and fuelling vessels. Marinas can be designed and maintained to ensure rapid clean-up of spills. Boat owners should use non-toxic cleaning products, clean and maintain boats away from the water, and prevent paint and other chemicals from entering the water (or stormwater drains) during maintenance. Keeping boats well tuned, carefully fuelling boat engines and recycling used oil helps to reduce petroleum pollution. Boat owners should aim to achieve zero discharge of sewage into estuaries by installing a suitable containment device.

What are people doing and what are they doing to the ecosystem?

Recreation and tourism are often assumed to have a relatively benign influence on the environment. Impacts are only noticed after many years of gradual decline (e.g. effects of toxic residues from boating). Establishing a cause and effect relationship between different activities and observed problems (such as algal growth, human health problems or declining fish catches) is seldom straightforward. Research into recreational impacts on estuarine ecosystems can help pinpoint the causes of such problems or pick up subtle effects before they develop into major issues. Then appropriate management actions can be taken. To help make zoning decisions and provide appropriate facilities so recreational activities have the minimum impact on an estuary, social research into how and where people recreate is important.

By monitoring people and selected ecosystem health indicators, managers can make informed decisions based measurable factors. This information is needed to help decide which recreational activities are appropriate for a particular estuary, whether or not to install or replace facilities or whether to regulate some activities. For instance, monitoring boat use at popular sites gives data that can help quantify any threat to those sites. Such monitoring also helps determine whether facilities such as moorings are needed to reduce threats like anchor damage to sea-floor habitat.

Where pathogens or toxic algae could be a health hazard, it is important to monitor regularly and give the public information on water quality. Quantity, type and origin of litter can be monitored. This can act as a basis for implementing targeted education and enforcement strategies. Above all, monitoring is important for tracking changes over time. This provides a basis for refining management strategies.

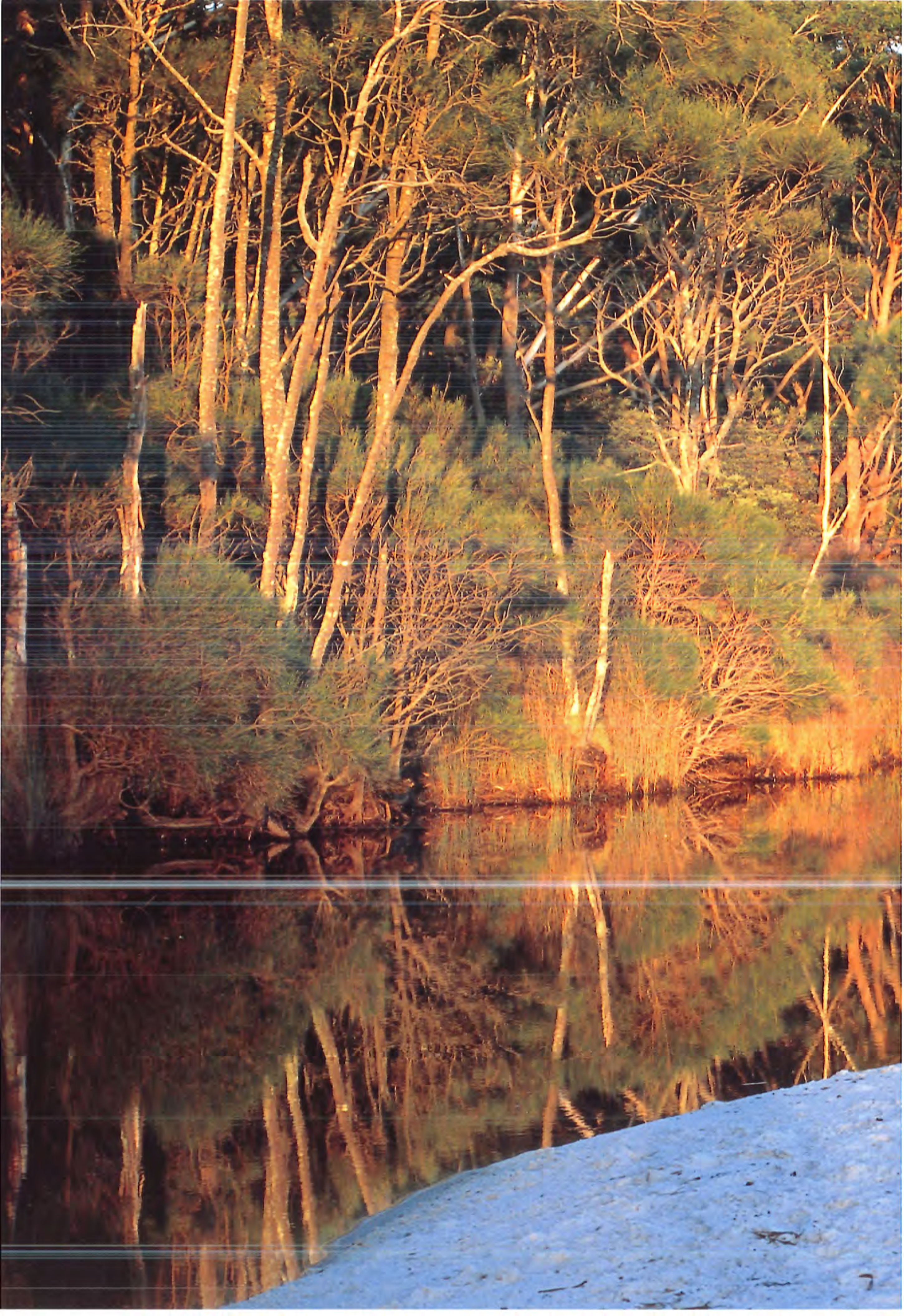
Tourism and recreation – good and poor practice

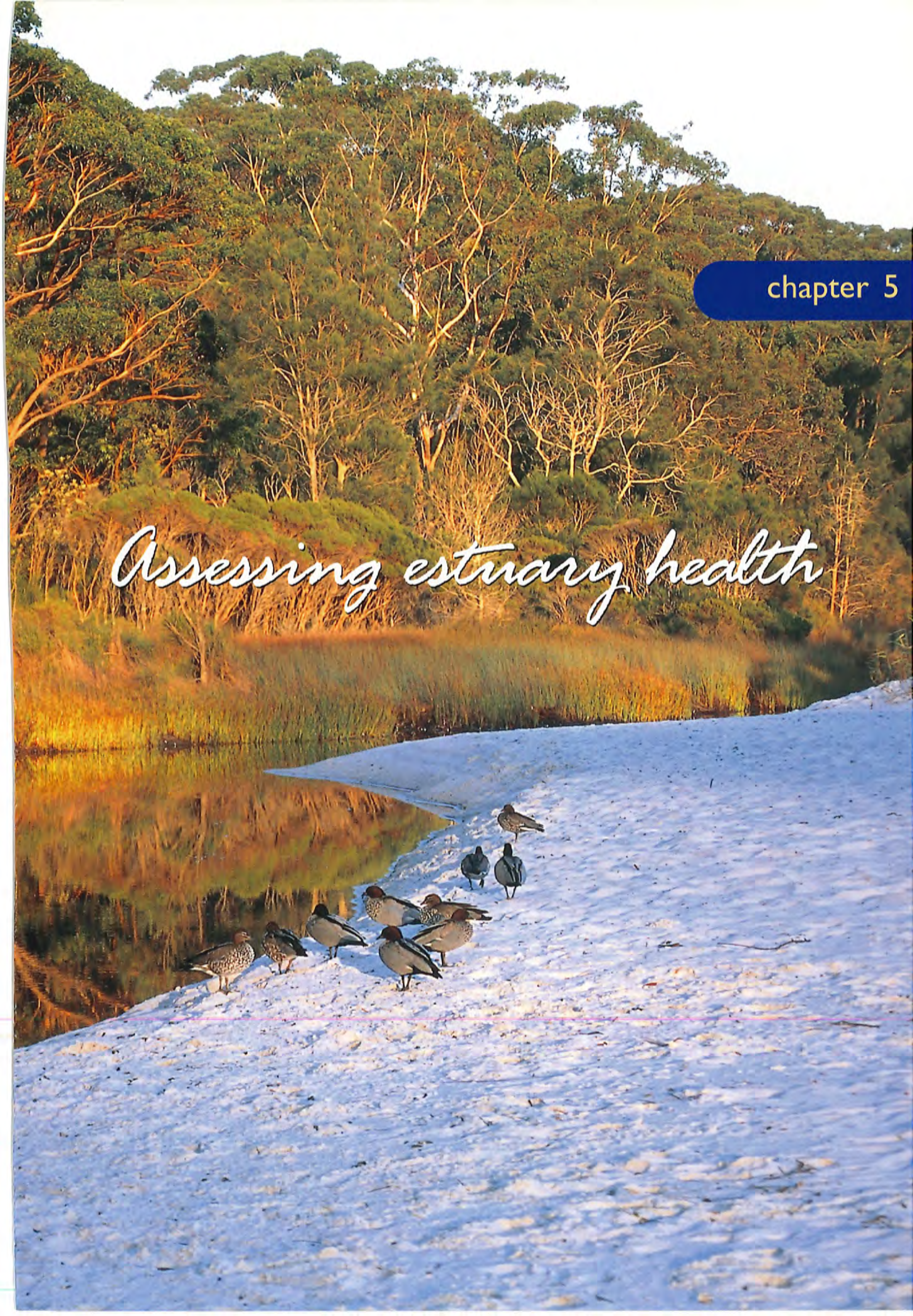
Good management practice

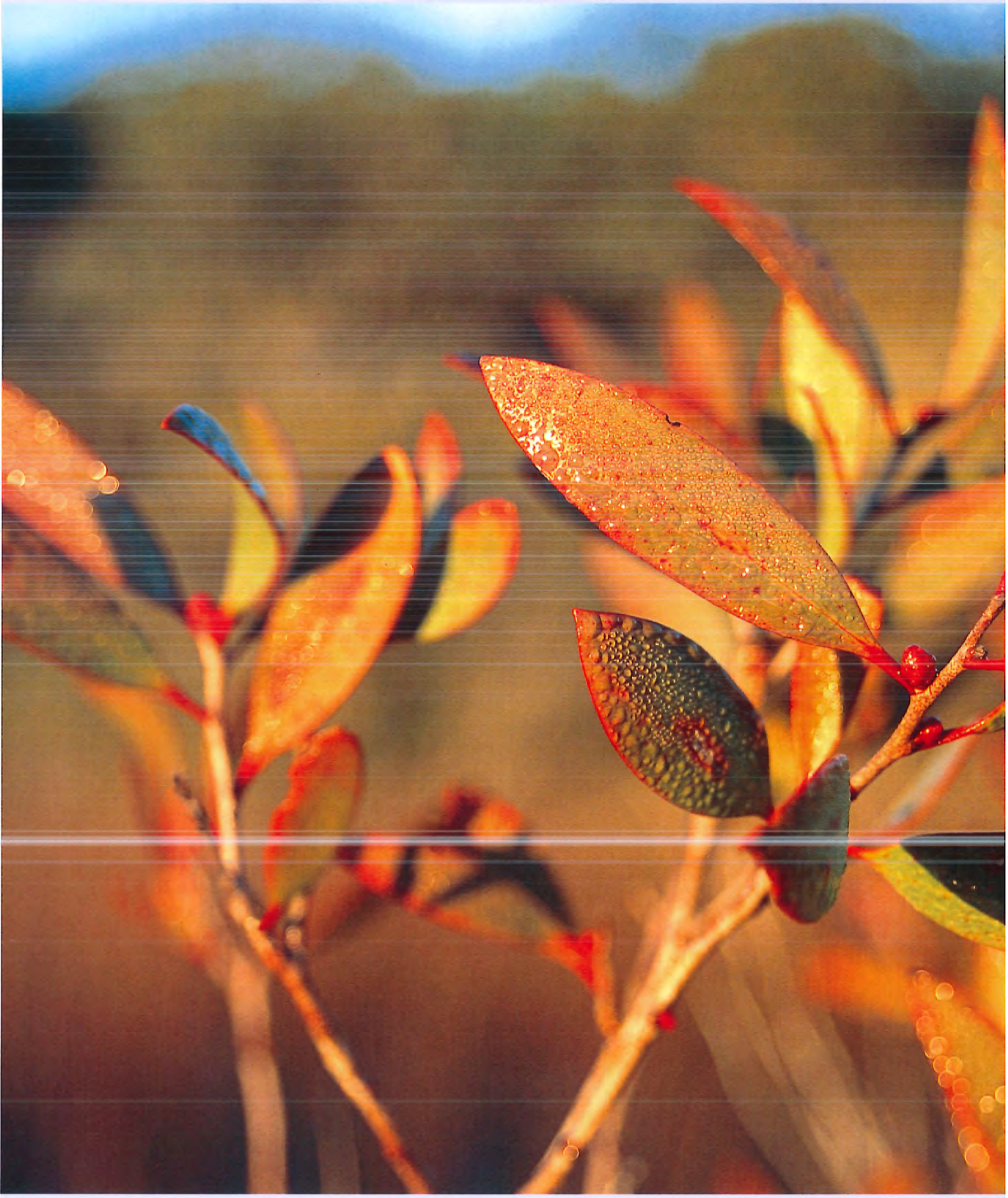
- Less invasive activities favoured
- High aesthetic value
- Large areas of original wetland preserved
- Presentation of wetland areas eg boardwalk access, information
- Ecological integrity of estuary intact
- Careful design and positioning of public amenities
- No litter
- Fish stocks attract recreational fishers
- Speed limits protect foreshore and other estuary users
- Good water quality encourages recreation eg swimming

Poor management practice

- Focus is on more invasive activities
- Infrastructure developed along foreshore
- Extensive habitat destruction for canal development
- Poorly positioned public amenities pollute estuary
- Chemicals from boat antifouling paint in sediment
- Litter threatens estuarine biota and aesthetic values
- Destruction of fish habitat threatens recreational fish stocks
- High speed water craft threaten animals and disturb other users
- Wash from high speed water craft erodes foreshore
- Poor water quality can threaten recreation e.g. pathogens




chapter 5
Assessing estuary health



What is a 'healthy' estuary?

Like human health, estuary health is difficult to define. When we refer to something or someone as 'healthy' we really mean there is no indication of problems. Typically when people talk about the 'health' of an estuary they are talking about ecosystem health. A healthy ecosystem is an environment that maintains its biodiversity, is stable over time, and is resilient to change. Scientists assess the health of an estuary by monitoring to determine if:

- the key environmental processes that operate to maintain a stable ecosystem are functioning
- human-impacted zones are improving or deteriorating further
- critical habitats such as seagrass beds are damaged, stable or recovering

Ecosystem health indicators

Indicators are useful to assess and compare estuaries. They provide information specifically on the health of an estuary rather than information about everything to do with the estuary. Effective ecosystem health indicators are simple, measurable, relevant and timely.

In selecting indicators to use it is important to know what questions you hope to answer. The steps in the process are:

- assess current state of knowledge
- identify key processes
- draw a conceptual diagram (that integrates current understanding with community-derived environmental values)
- test and refine indicators and conceptual diagrams

Why do we assess estuary health?

We have seen from the previous chapter that Australia's estuaries are important to our economy, our health and our social wellbeing. The rapid expansion of coastal population centres reflects our growing dependence on the economic, recreational and aesthetic benefits that estuaries provide. However, as a result of this expansion many of the ecological processes within our estuaries (discussed in Chapter 3 *Estuary habitats*) are being severely compromised. We depend on healthy estuaries for a range of economic, recreational and aesthetic benefits.

Estuarine ecosystem assessments help us manage our estuaries well. We monitor to determine whether we are progressing towards our objectives, goals and vision. Monitoring must be tailored to develop the understanding and to supply the information needed for decision-making. Every monitoring action should have a clear purpose and a definite target. Because monitoring occurs over an extended period of time it can be very expensive. Monitoring programmes should designed and run to ensure they are affordable and lead to effective decision-making.

We depend on healthy estuaries for a range of economic, recreational and aesthetic benefits

Management agencies, community groups and industry monitor the health of estuaries to identify problems before it is too late to fix them. Some monitoring is required by law. The questions that monitoring programs typically are designed to answer include:

- Is the health of our estuaries improving or deteriorating?
- Are the changes related to human activity?
- Do some activities (e.g. agriculture, industry, sewage treatment) have more impact than others?
- What actions can best correct existing (or prevent future) problems?

Monitoring gives important information about the condition of estuaries and the consequences of human activity. Since the 1980s, millions of dollars have been spent monitoring changes to rivers, estuaries and wetlands. As the pressures on the coast inensify, new approaches to environmental monitoring will be needed. The challenge for estuary managers is to use this information to balance economic development with the need to ensure healthy estuaries for future generations.

Estuary assessment tools

To better understand how to assess the health of an estuary, we can look at how we monitor and assess our own health. Humans monitor a range of indicators such as the presence of pain, a general feeling of wellbeing, our pulse rate and body temperature. Changes in these indicators give us early warning of potential health problems. More detailed 'monitoring' or tests may be needed to pinpoint the problem. If we do not leave it too long to address the problem, then there is a good chance we can fix it before it becomes serious.

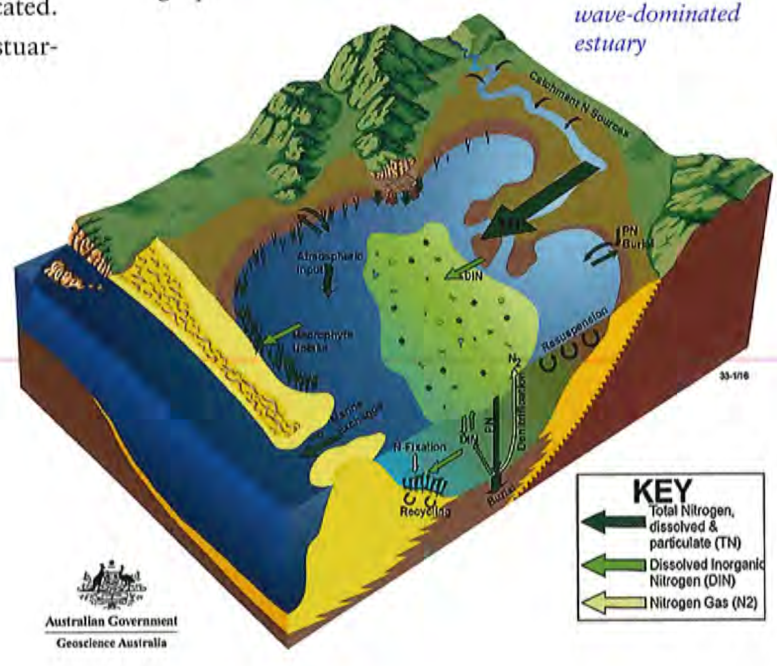
In estuaries, health indicators may include habitat integrity, water and sediment quality and fish health. Science supplies knowledge and tools to help manage estuaries sustainably. These tools must be updated as more and more sophisticated questions are being asked of estuary managers. It is important that managers use the most appropriate tool for the job, be it simple or sophisticated. Tools to help assess and manage estuaries include:

- conceptual diagrams
- classification systems
- field studies
- remote sensing
- case studies
- numerical models with predictive capability

Conceptual diagrams

Conceptual diagrams are potentially very useful to the estuary manager because they distil complex ideas. Simple diagrams can provide a framework for explaining processes and interpreting results. They also help explain why an approach used for, say, monitoring in one estuary, is not appropriate for use in another. There are many different types of conceptual diagrams. The illustrations used in Chapter 1 to explain the different types of estuaries as well as the diagrams with the case studies in Chapters 6 to 12 are conceptual diagrams. Conceptual diagrams are used to:

- communicate the key inputs and processes, impacts and biotic features
- prioritise future strategy, research and monitoring efforts
- synthesise divergent results into a single picture



A conceptual diagram of nutrient movements in a wave-dominated estuary

Classifying estuaries

One way to simplify the diversity of estuaries for the purposes of understanding how they work is to classify them. Here, estuaries (or parts of estuaries) are grouped on the basis of how they formed and what controls their function. *The National Land and Water Resources Audit Estuary Assessment 2002* classified Australian estuaries by the extent to which wave, tide or river energy drives the way the estuary works. Chapter 1, provides more information on the classification of Australian estuaries used in the audit.

Once you know the type of estuary you have, it is easier to understand how it behaves and therefore what information might be needed to manage the estuary. For example, wave-dominated estuaries have naturally low turbidity so an increase in turbidity may be a sign of problems. Whereas, tide-dominated systems are naturally highly turbid, so turbidity is a less meaningful measure (see the table on page 18, Chapter 1 *What is an estuary?*).

A scientist studies Moreton Bay seagrass close-up.

Field investigations

Field studies provide the backbone of our scientific knowledge. From these we learn how estuaries work. Scientists are continually improving equipment and methods for this purpose and using the data to check numerical models which predict estuary behaviour under a variety of conditions.

Remote sensing

Remote sensing has been used in coastal environments for many years. A range of remotely-sensed data are available to cover small areas in detail or the entire Earth in a day, with sensors designed specifically for monitoring vegetation or water-quality. Remote sensing measures light and other forms of radiation (such as radar waves) reflected from land and sea. The sensors are carried in aircraft or satellites. Remote sensing allows the extent and characteristics of vegetation, soil, atmospheric and aquatic features to be studied. The chemical, biological and structural characteristics of these features interact with light and can be measured by the sensors. Remoting sensing allows rapid monitoring of changes in natural conditions, such as an algal bloom or flood, over large areas. To assess the accuracy of remote sensing, known sites with a feature, such as mangroves, are matched with their appearance in a remotely-sensed image. Alternatively, measurements of features, such as water turbidity at different locations, are correlated with values in the image of the area. Remote sensing and field sampling are combined to provide accurate information for assessing ecosystem health.

Case studies

Case studies give site-specific information. For example, the case studies presented in this book give examples of what can happen to estuaries when we alter the way they work, decreasing freshwater flows or tidal flushing or increasing the sediments and nutrients delivered to them from catchments.

Numerical and predictive models

One of the more powerful tools estuary managers have at their disposal is the numerical (computer) model. Combined with field studies and remotely-sensed data, numerical models can be used to tell us more about the processes in estuarine systems and to predict the consequences of, for instance, changing land use in the surrounding catchment. One advantage of numerical models is that they are able to provide information over wide spatial scales. Another important point is that the results can be expressed in an easily understandable framework that is, no equations, no graphs, but as still pictures or animation with geographic references. Members of the public can see where their houses and their favourite shellfish beds are situated in relation to a predicted effect. Estuary managers can investigate how an estuary may respond to various changes.

An example is the Simple Estuarine Response Model (SERM), which lets environmental scientists and stakeholders explore the ecological behaviour of estuaries on the Australian continent. Developed by CSIRO and the Coastal CRC as part of the *National Land and Water Resources Audit*, SERM represents a first attempt to extend current models to the broad range of Australian estuaries. SERM results can be accessed through the Internet using a standard web browser at http://www.marine.csiro.au/serm2/. The SERM website encourages the user to experiment – explore the effects of changing point-source loads, catchment condition and freshwater flow rates – to better understand the ecological dynamics of estuaries and their responses to human pressures.

A remotely-sensed image of Moreton Bay in southeast Queensland

Monitoring challenges and trends

Measuring ecosystem condition

It is challenging to measure the overall 'condition' of an ecosystem. Unlike a living creature, which might be either healthy or unhealthy but cannot be both simultaneously, ecosystems can be in good condition for producing certain goods and services while in poor condition for others. In Chapter 4 we discussed some of the ecosystem goods (such as fish and genetic resources) and services (such as water purification, flood control, coastline stabilisation, waste treatment, biodiversity conservation and the aesthetic and cultural benefits estuaries provide). Typically, we manage ecosystems to increase the production of one or more goods and services, such as food and shipping, at the expense of others such as water quality or biodiversity. We thus make trade-offs among the different goods and services.

Scientist tests stormwater, Lota Creek, Brisbane

Ecosystem condition can be measured by comparing one or more properties (such as biomass, number of species, or nutrient flow) to those of a 'natural' or undisturbed ecosystem, thereby defining 'condition' to be the degree of non-naturalness. That is the approach that was taken by the *National Land and Water Resources Audit Estuary Assessment*.

Another approach is to assess separately the capacity of the system to provide each of the various goods and services and then to evaluate trade-offs among those goods and services. This type of integrated ecosystem assessment includes both ecological and economic analysis. It considers both the current state of the ecosystem and its future potential.

Geography

Natural forces push estuaries from both ends – catchment activities and processes from one end and ocean processes from the other – so any estuary assessment must consider both sets of processes. What goes on in the estuary and how it copes with human impacts depends, in part, on how the balance between these forces fluctuates. This will vary with different types of estuaries so it is important to recognise the type of system and its properties at an early stage in any study.

Time

Estuary assessments must take into account a wide range of timescales. For instance, when a river floods or strong winds whip up waves in a shallow estuary, the water becomes turbid within hours. However, it will take days or weeks to clear again. Floods may leave layers of mud on the sandflats and it could be months or years before waves, tides and biological processes disperse this material. At longer timescales, sand moves about in giant loops between flood- and ebb-tidal shoals and adjacent beaches. These sand movements are driven by tides and waves. The wave climate in turn may be subject to El Niño and La Niña cycles and long-term climate change. Resource managers may need information measured over decades. If there is no such data available, information will have to be deduced from measurements made over shorter timescales.

Skills and expertise

To assess estuaries effectively we need information from many disciplines. Questions about sustainable management tend to be interdisciplinary by nature. Studies of biological, physical and chemical processes are needed to solve problems. Integrating information from different disciplines is not as straightforward as it might seem. This is because the type of information that, say, physical oceanographers and benthic ecologists collect, are very different. Both parties have good a understanding of environmental processes, but their understanding derives from different perspectives. While both work in the same physical environment and the biology is determined to some degree by physical processes, the biological picture is further complicated by biological interactions.

The people who live and work in an estuary will see changes over time. The knowledge and information of the local people and traditional owners is invaluable for understanding an estuary and interpreting the results of monitoring. Economists and social scientists can assess the social and economic implications to changes in estuary health and help to change the way we interact with our estuaries and the environment.

The importance of scale

Yet another difficulty in assessing the condition of an ecosystem is the issue of scale. For any size patch of the Earth's surface that we choose to call an ecosystem, there will be a set of factors outside the ecosystem that influence how it functions and, in turn, there will be flows of material and energy, as well as various goods and services, that extend beyond the ecosystem. For example, estuaries are strongly influenced by nutrients and sediments exported from upstream, sometimes thousands of kilometres away. The larger the scale of an assessment, the more inclusive it is of these flows of material and energy. However, assessments undertaken at larger scales lose the site detail that managers often need if they

Researchers investigating estuary condition are to take action. Certain types of estuary information are most relevant at the national scale, such as information on littoral sand drift, estuary reserves, introduced marine pests and migratory birds, while other information, such as water quality, will be most relevant at regional or local scales.

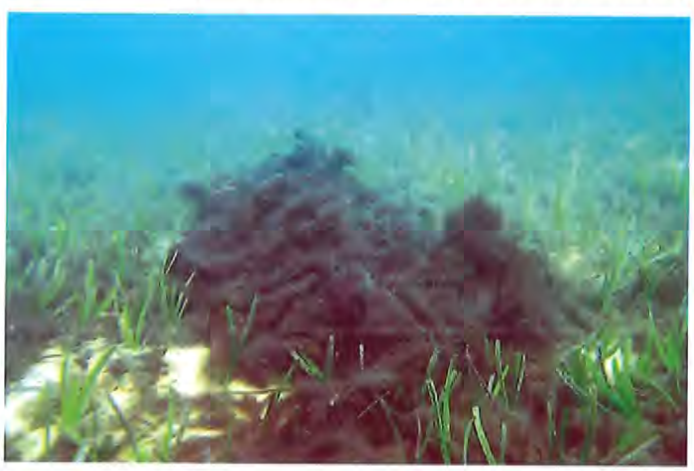
An abundance of indicators, a scarcity of meaning

The ecosystem 'indicators' that are most readily available, and which have shaped our current understanding of ecosystems, are far from complete. They each give us only a partial description of the bigger picture. These indicators include:

- pressures on ecosystems, including such factors as population growth, increased resource consumption, pollution and overharvesting
- extent of ecosystems
- production or output of various economically important goods by the system, such as crops, timber or fisheries production

Each of these indicators is important but collectively they provide only a narrow window on the question of how well our estuaries are being managed. Pressure alone, for example, does not reveal the actual state of the system. With proper management, an ecosystem can withstand significant pressures without losing its productivity.

The presence of Lyngbya majiscula *is an indicator of pressure on the estuarine water quality in Moreton Bay*



None of these traditional indicators tell us about the underlying condition or health of the ecosystem. Knowing the condition or state of the ecosystem is as important for policymaking and planning as knowing what it is producing. Surprisingly, the availability of information for assessing the condition of estuaries has not improved in recent years as might be expected and may even be shrinking. Remote sensing has increased information about certain features of ecosystems, such as their extent. Field information for such indicators as freshwater quality and river discharge is less available today than 20 years ago, largely because funding has diminished for the once-extensive systems of environmental monitoring and record-keeping that existed around the country several decades ago.

Sometimes even where data are available, we don't yet have enough scientific understanding of how changes in biological systems will affect the goods and services produced and vice versa. The Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management (www.coastal.crc.org.au) and the Fisheries Research and Development Corporation (www.frdc.com.au) are supporting the science needed for better decision-making.

Assessing the health of Australia's estuaries

In 2002, the *National Land and Water Resources Audit Estuary Assessment* collated data on 974 Australian estuaries in order to:

- assess the condition of Australia's estuaries
- classify the different types of Australian estuaries
- contribute to an information base to support estuary management

The condition assessment gives a broad picture of Australia's estuaries and how seriously human activities have affected them. Used with the process-based classification, this assessment gives important information on the conservation significance of estuaries. Many of the near-pristine estuaries are tidal flats and creeks.

Assessment was based on change from pre-European (1770) condition with the assumption that a healthy estuary can support a range of beneficial uses. The assessment was done in two parts.

Initial qualitative condition assessment

Australia's near-pristine estuaries were identified through a series of state-based workshops. The assessment criteria included:

- catchment natural cover
- land use
- catchment hydrology
- tidal regime
- floodplain condition
- estuary use
- pests and weeds
- estuarine ecology

More quantitative condition assessment

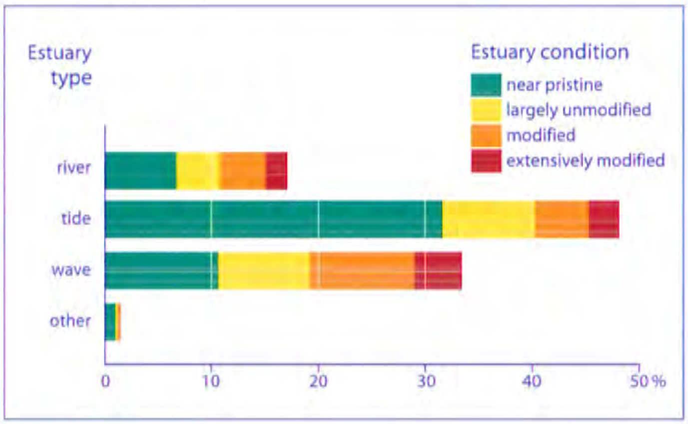
More challenging than assessing pristine estuaries is determining the extent of change for the modified estuaries, particularly given the limited amount of information available. A number of approaches could be used to establish the state or condition of an estuary. Our uses, values and perspectives bias any assessment. A pressure–state–response framework was used in this assessment. It included the criteria used in the qualitative near-pristine estuary assessment but made an attempt to quantify as much of the information as possible. The 'state' component of the assessment used an ecosystem health perspective rather than that of any particular individual or group of beneficial uses. The rationale was that a healthy ecosystem can support a number of beneficial uses. The aim of the assessment was to identify the management needs of Australia's estuaries. Some problems arise because not all beneficial uses of particular estuaries are socially desirable or economically viable to restore.

The table below shows the pressure–state–response framework used for the 2002 estuary assessment

	What was measured?	Weight	Ranks			
State ranking	Ecosystem integrity Water & sediment quality Fish health Habitat condition	70% 10% 10% 10%	Near pristine	Largely unmodified	Modified	Extensively modified
Pressure ranking	Amount of estuary use Susceptibility of estuary to impacts	50% 50%	low – no pressure	low – medium pressure	medium – high pressure	high – very high pressure
Response	The actions being taken by various responsible agencies and by communities, to meet estuary management needs, were documented but not ranked					

Key findings: what is the condition of Australia's estuaries?

Australia's estuaries by type and condition. Tidal estuaries dominate and are generally in better condition with over half near pristine.



A near pristine estuary on Fraser Island. The estuary has a very small catchment and is in a national park.

The results of the *National Land and Water Resources Audit Estuary Assessment* 2002 are reported throughout this book in the bar graphs for each region and state. The condition of all estuaries assessed is given below.

The 974 estuaries assessed nationally were found to be:

- 50% in near-pristine condition
- 22% in largely unmodified condition
- 17% in modified condition
- 1% in extensively modified condition

Not surprisingly, most of Australia's near-pristine estuaries are away from population centres. The highest proportion of near-pristine estuaries is in tropical northern Australia and temperate western Tasmania. Important near-pristine estuaries are also found around developed areas of Australia, often within or near to managed public lands such as national parks. Not all estuary types are well represented within the near-pristine estuaries. The majority of estuaries in near-pristine condition have very small catchments.

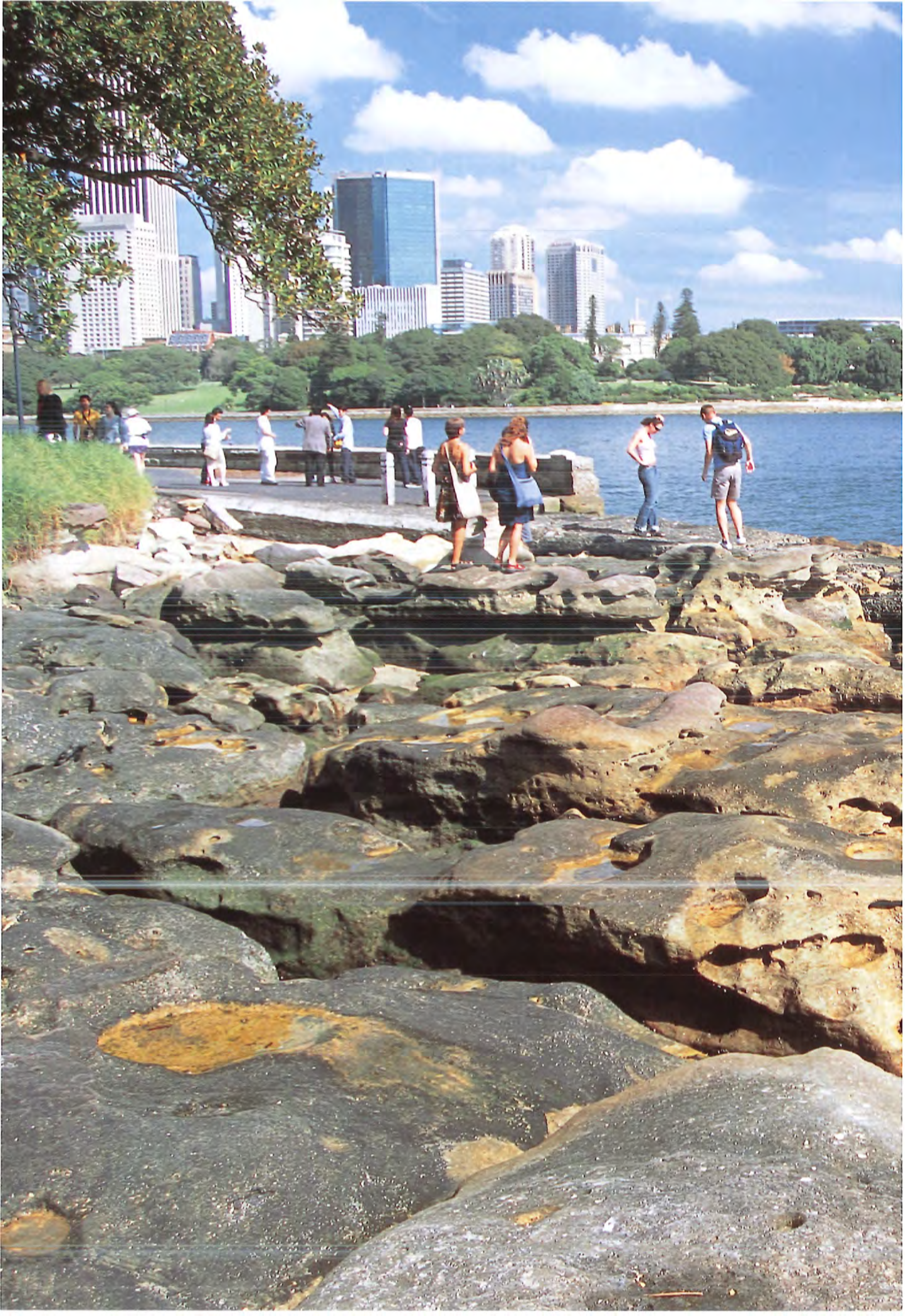
The fact that so many of the estuaries are in near-pristine and largely unmodified condition reflects the large number of Australian estuaries (over 40%) that have very small catchments, often less than 15 km^2, and the remoteness of many of these systems. A closer investigation reveals that estuaries near population centres, and downstream of agricultural and urbanised catchments, are typically extensively modified and have many symptoms of severe environmental damage such as chronic algal blooms. The modified estuaries were assessed both in terms of their current condition and the pressure they face in relation to the beneficial uses they provide.

Bringing science and management together

Monitoring is useful if it helps us reach better decisions. Monitoring is as much about communication as it is measurement. Estuary managers have the right to expect scientists to be able to explain what they are doing and why, in simple and understandable terms. However, estuary managers must appreciate that simple (and cheap) science will probably not answer their questions. Even the simplest ideas or diagrams have a history involving research and expert knowledge. As you will see in the chapters to come, estuaries are all different and it is rarely possible simply to transfer results from one place to the next. Effective estuary management is a complex and often costly business. It requires an adaptive management approach where estuary assessments both inform and are informed by management actions.

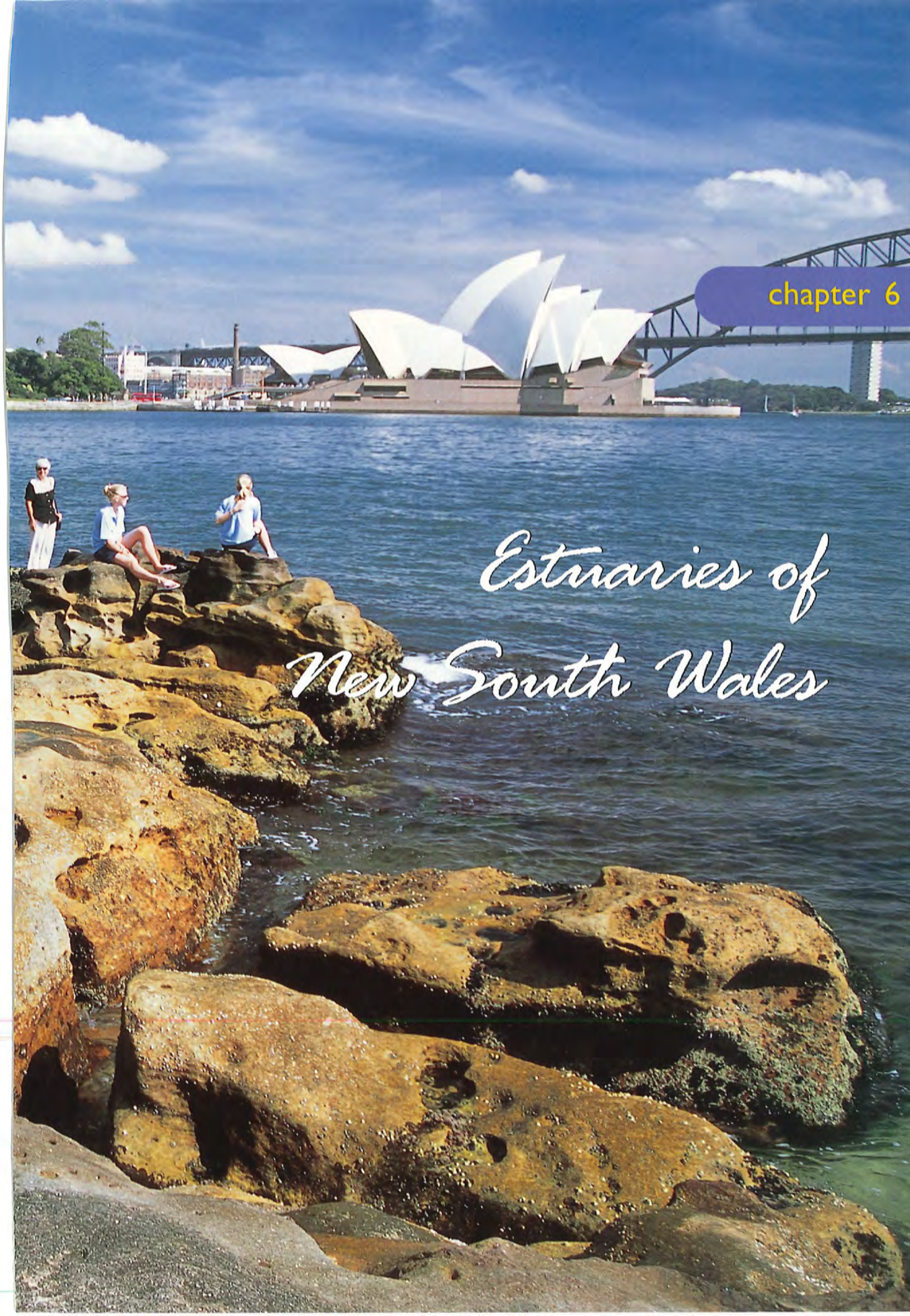
Scientists must clearly communicate their findings to estuary managers if their research is to translate into action (right).

Assessing the condition of seagrass in Moreton Bay (below)



chapter 6

Estuaries of New South Wales



Hormosira banksii

Most estuaries in New South Wales are under threat from intense urban development pressures. Approximately 80 percent of the state's population lives near an estuary. Some 60 percent of the state's estuaries are intermittently closed or open lakes and lagoons (ICOLLs) with ecosystems sensitive to catchment land use activities and competing estuary uses. The New South Wales Estuary Management Program was introduced in 1992 as a partnership between the State and local government to resolve conflict within local communities over use of limited estuary natural resources and to assist local government to prepare and implement sustainable estuary management plans for the protection of estuaries and, where necessary, their rehabilitation.

Today (2004) a Coastal Zone Management Manual is being prepared to provide improved integrated management of the New South Wales Coastal Zone. The manual offers communities a proven process to address critical estuary management issues and develop cost-effective solutions. While there is strong community support for developing sustainable estuary management plans and implementing protective planning strategies, the rehabilitation of estuaries in poor health is often beyond the financial and technical resources of local councils and state government. Gaps in estuary information and field data also mean that complex natural biophysical processes are poorly understood. This makes it difficult to select the best management solutions. More resources and greater integration of estuary information monitoring and research effort is needed to address these problems. A planning strategy for coastal catchments must bring together estuary managers and scientists with relevant disciplines, so complex processes in estuaries are understood and management strategies are applied to protect their health in the future. The condition of an estuary provides a good indicator of catchment health.

Regions

- *Far North Coast*

  (from Tweed River to Sandon River)

- *Mid North Coast*

  (from Wooli Wooli River to Hastings River)

- *North Coast*

  (from Lakes Cathie/Innes to Hunter River)

- *Sydney Region*

  (from Lake Macquarie to Minnamurra River)

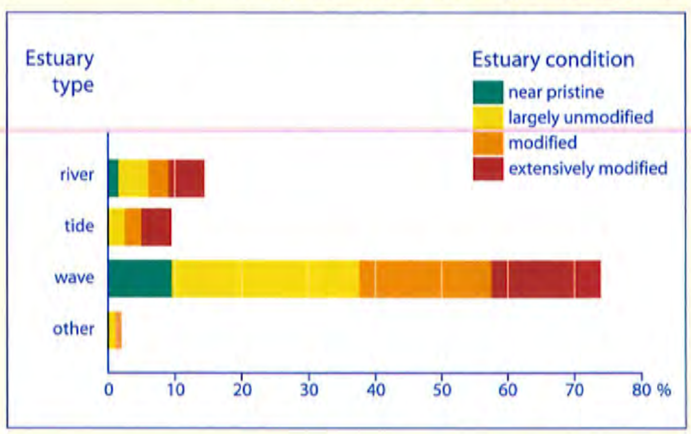
- *South Coast*

  (from Werri Lagoon to Tuross Lake)

- *Far South Coast*

  (from Lake Brunderee to Nadgee Lake)

Estuaries of New South Wales – type and condition

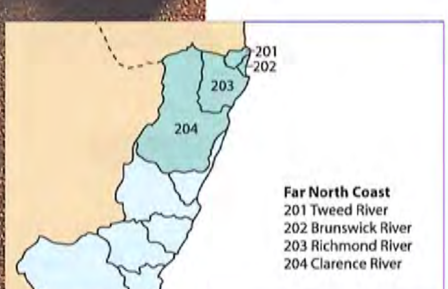


NSW Far North Coast

Green catchments and sandbars

Cudgera Creek bar

The far north coast estuaries extend from the Tweed River at the Queensland border south to the Sandon River near Grafton. The region has a series of large river valleys and floodplains, separated by areas of narrower coastal plain with small coastal lagoon and strandplain systems. Ocean waves drive sand northward along the New South Wales coast building sandy barriers across the mouths of these estuaries. The river valleys and flats are prone to flooding. Rainfall is relatively high, ranging from about 1000 to 1800 mm per year and, though spread throughout the year, is highest in the January to June period. Patches of rainforest are found on the eastern slopes of the Great Dividing Range. The extensive Clarence River system runs from the tablelands near Tenterfield and Dorrigo through the slopes onto the lower floodplain and estuary near Copmanhurst, draining to the ocean at Yamba-Iluka.



The region supports wetland habitat important for aquatic and terrestrial fauna. Patches of seagrass are found in a number of estuaries, while the Clarence River has the second largest area of estuarine seagrass in New South Wales. This helps support the most productive estuarine fishery in the state. Most estuaries in the far north of New South Wales have mangroves and saltmarsh, with six mangrove species found in the region. A range of other brackish and freshwater wetlands is also present.

Farmers and fishers

This region offers a unique lifestyle with pristine surf beaches, unspoilt rainforest and wild rivers. Six of Australia's World Heritage listed areas are found here. Four large coastal rivers are located in the region – the Tweed, Brunswick, Richmond and Clarence rivers.

The area has extensive rural floodplains supporting grazing, dairying and sugar farming, but it also caters for a major influx of tourists during the summer months. Scattered throughout the area are small towns, villages and rural settlements.

Urban centres include Tweed Heads, Brunswick Heads, Ballina, Yamba and Iluka providing a range of tourist facilities, fishing ports and recreational pursuits. Exceptional recreational fishing and some of New South Wales' best surfing beaches are a prime attraction.

The region's cultural mix has produced a thriving visual and performing arts community. Unique townships such as Byron Bay encourage the arts and alternative lifestyles. An abundance of fetes, fairs and festivals promote the region's vibrant and unique culture.

Houses on the floodplain, cows in the catchment

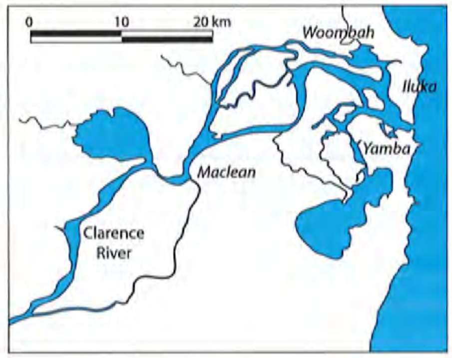
Most catchments have been modified for agriculture. Cane farming is the main land use on the larger river flats. Areas with rich volcanic soils support mixed cropping and horticulture, as well as dairy and beef cattle grazing. There are significant national parks and reserves. Several estuaries in the southern part of the region are in near-pristine condition. The larger estuaries have been permanently opened with twin breakwaters and limited navigational dredging to support commercial fishing. A number of estuaries support fish, prawn and oyster production. The Clarence River is the most productive estuarine fishery in New South Wales (valued at $4.7 million in 1998–99) boasting the highest catch of mudcrab in the state and producing sea mullet, school prawns, sand mullet, black and yellowfin bream. The Richmond and Tweed Rivers are also important fisheries. Commercial species include sea mullet, school prawns, fantail mullet, longfin eel, sand whiting and mudcrab. Recreational activities such as surfing, canoeing, bushwalking, fishing and camping are popular.

Important issues for the region's estuaries include development of the coastal strip and associated habitat loss, competing uses for natural resources and decline in seagrass. Other concerns include acidification of estuaries (acid sulfate soils), sand extraction, eutrophication of coastal lakes and deposit of silt eroded from farmland. Urban and rural residential development has the potential to increase pollution from stormwater run-off and sewage disposal. Estuaries are affected by changes to river flows from urban and agricultural dams and hydroelectricity generation. Flood mitigation structures and floodplain drainage works, designed to protect towns and support floodplain agriculture, can also have adverse affects on stream flow, wetlands and fish movements. As well, these works can expose acid sulfate soils.

Dairying in the catchment of the Tweed River

Cane growing on the Tweed floodplain

Case study: Clarence River



The Clarence is one of the major coastal rivers of New South Wales and its large delta is subject to repeated and extensive flooding. The Clarence system is around 680 km north of Sydney. It feeds a broad fertile floodplain before discharging to the sea at Yamba.

The tidal section of the lower river and estuary extends about 105 km upstream from the mouth. Within this section, the river has a well-defined main channel. Downstream of Ulmarra (some 50 km from the sea) the main channel connects a series of relict backwater channels and broad basins (The Broadwater and Wooloweyah Lagoon) that form the lower river delta. The region experiences high rainfall. Major downpours that cause serious floods in the lowland plain are not uncommon.

Since early European settlement, the influence of human activities has changed as modes of transport, agricultural practices and the local economy have evolved. Early settlers used the river to transport timber. Around this time, clearing of the lower floodplain river flats commenced and small settlements were established along the river. Clearing of the fertile river lowlands and lower slopes has continued for sugar cane and cattle grazing. Large wetland areas of the lowland plain have been drained and converted to agricultural use. The waterway is also an important fishing area.

The lower floodplain soils are typical of north coast river soils and are highly acid forming when disturbed. Clearing woodlands and draining low-lying wetlands have increased acid run-off to the estuary. The result is lower pH in waters next to the drains and creeks. Acid impact on estuarine waters has not been measured other than observation of fish kills and disruption to oyster production.

The first entrance training works were undertaken in the 1860s with realignment of the entrance channels continuing until the 1960s. Generally, today's entrance is deeper than before training wall construction. This has probably led to an increase in the volume of water drawn into the estuary during flood tide (the tidal prism). The rock reef at the entrance, which has high Aboriginal heritage significance, restricts navigation. Urbanisation has centred on Grafton, Maclean, Iluka and Yamba.

Today the Clarence River supports a healthy economy of sugar cane, tourism, aquaculture, fishing and cattle grazing. Major issues affecting the estuary include deterioration of water quality, sedimentation and erosion, declining fish stocks and disappearing seagrass habitats. Acid soils run-off, dredging and flood mitigation levees, loss of riparian vegetation and lack of public amenity are other concerns.

Significant amounts of sediment move through the entrance. Marine sands come in on flood tides during ocean storms. The river sands mix with marine sediments in the lower estuary and are expelled from the estuary only during very large floods when the entrance is scoured. Catchment clearing and loss of riparian vegetation is estimated to have increased sediment yield between 200 percent and 400 percent since European settlement.

Fifty years of aerial photographs show a small loss of mangrove habitats and saltmarsh areas and a significant loss of seagrass (more than 60%). The seagrass decline is most likely associated with an increase in turbidity due to larger loads of very fine sediments.

Oyster racks, Yamba

Recreational craft in Yamba marina (below); breakwaters, at the mouth of the Clarence River (facing page)

NSW Mid North Coast

Coastal creeks

The mid north coast includes estuaries from Wooli Wooli River near Grafton to Hastings River at Port Macquarie. The coast is wave-dominated. Longshore sand movement has barred entrances. The area has several large river floodplains with steeper sections between, where the Great Divide approaches the coast. Steep lands to the west are drained by the Nambucca, Macleay, Hastings and Camden Haven rivers. Smaller coastal lakes, lagoons and strandplains include several in national parks and reserves. Yearly rainfall averages 1000–1500 mm. Summer and autumn months are wettest.

Many of these estuaries support seagrass, especially the Macleay and Hastings. Mangrove and saltmarsh habitats also occur here. Of the mangrove species found in this district, only Wooli Wooli River supports all four.

Coastal communities: grommets and oysters

This area boasts popular holiday meccas such as Coffs Harbour, South West Rocks and Port Macquarie. Pristine, golden sandy beaches include stretches at New Haven, Crowdy Bay, Dunbogan, and Nambucca Heads. Many more remote coves, inlets and bays are scattered along the coast.

Within a day's drive of Sydney, the area is favoured for holidays. Populations of some coastal towns double during peak season. The area is also a popular retirement destination with a pleasant climate and modern facilities at key coastal towns.

Twelve national parks in the area plus many council parks and reserves provide picnicking and bushwalking opportunities. The mid north coast is renowned for seafood with many restaurants, clubs and pubs catering for tourist needs. Oyster farming in the Hastings River meets local and state demands.

Pathogens and nutrients from sewage

This region includes significant national parks and nature reserves and popular tourist areas such as Port Macquarie at the mouth of the Hastings River. The estuaries are important for spat catching and oyster production and commercial fishing and prawning. Recreational fishing is a favourite pastime. These attractions have encouraged urban development, including canal developments in the past. Bananas are grown on steep hillsides in the Coffs Harbour–Nambucca Heads area. Other local industries include dairy cattle and timber. The Hastings and Macleay rivers support commercial fisheries that include sea mullet, luderick, school prawn and mudcrab and are large oyster producers. Acid sulfate soils have been disturbed by drainage and flood mitigation works.

Case study: Hastings River

The port abounds with fish, the sharks were larger and more numerous than I have ever before observed. The forest hills and rising grounds abounded with large kangaroos and the marshes afford shelter and support to innumerable wild fowl. Independent of the Hastings River, the area is generally well watered, there is a fine spring at the very entrance to the Port.

John Oxley, 1818

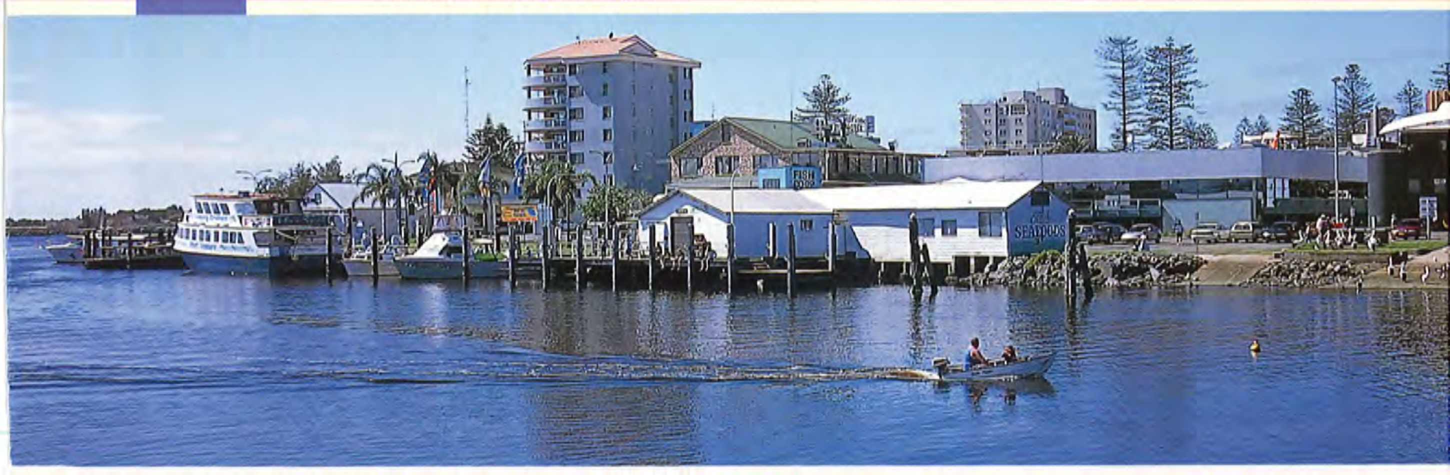
The Hastings River estuary is a wave-dominated delta, tidal to about 32 km upstream from the entrance at Port Macquarie. The Hastings River and Port Macquarie were named by John Oxley who explored to the mouth of the river in 1818. Oxley reported an area suitable for cultivation of "tropical fruits and plants". In 1823 the first sugar cane cultivated in Australia was planted here.

The shallow entrance bar prevented Port Macquarie from emerging as a major port. The town, located south of the river entrance, grew slowly as a regional commercial centre until the 1970s when a population explosion turned it into a major tourist and retirement destination. Port Macquarie, with over 35,000 residents, is now the largest town on the New South Wales coast between Newcastle and Tweed Heads. People are drawn by the mild climate, exceptional beaches and amateur fishing opportunities. Species caught include bream, flathead, jewfish, tailor and whiting. Surfing, swimming, windsurfing, boat hire and river cruises are also popular. A major canal sub-division (Port Shores) and marina have been built on the estuary. Twin training walls at the entrance help keep the waterway navigable.

The Hastings River is a large oyster producer, with some commercial fishing and prawning also occurring. Among industries represented in the catchment are forestry, agriculture, including dairying, and a small winery on the river west of Port Macquarie. There are several national parks and nature reserves.

Acid sulfate soils are an important issue, with acid run-off from soils disturbed by the drainage and flood mitigation systems along the southern shore of the river. Otherwise water quality in the estuary is good. There are some localised water quality problems, particularly after heavy rain, as a result of catchment land use and the two treated sewage effluent inflows at Wauchope and Port Macquarie. These problems include turbidity, sedimentation, eutrophication and bacterial contamination.

Hastings River, Port Macquarie

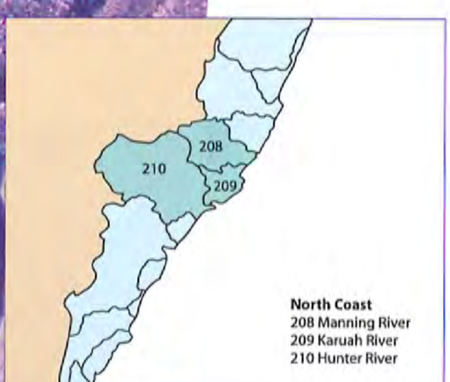


NSW North Coast

Broad estuaries in a coastal floodplain

The north coast region includes the estuaries from Lake Cathie/Lake Innes south of Port Macquarie south to the Hunter River near Maitland. It is characterised by wide floodplains and coastal sandplains. The expansive Hunter Valley extends inland for about 70–80 km from the port at Newcastle. Coastal rainfall is about 1000–1300 mm per year, but the upper Hunter Valley is drier, receiving as little as 600 mm in areas. The estuaries in this region include several vast, complex systems of interconnecting lakes and channels with extensive areas of wetland habitat.

There are Ramsar significant wetlands at Kooragang Island (Hunter River) that provide key migratory bird habitat. Saltmarsh is an important component of these estuaries. Many of the largest areas of saltmarsh in New South Wales are found in the region, including in Port Stephens, Lakes Cathie/Innes, the Hunter River and Karuah River. Saltmarsh areas often grade into freshwater and brackish swamp forests dominated by *Melaleuca* and *Casuarina* species, with an understorey of sedges, reeds and rushes. Freshwater swamps and other wetlands form fringing communities in the upper reaches of these complex estuarine systems. Mangroves are also found in most estuaries, though not in Khappinghat Creek or Smiths Lake. Three mangrove species are found in the region, which includes the largest mangrove stands in New South Wales in Port Stephens and the Hunter River. The extensive seagrass beds in Wallis Lake comprise about 20 percent of the total seagrass in New South Wales. These plant communities provide habitat for some of the most productive estuarine fisheries in the state.



Wine, food and song

The area has some of the largest scenic coastal lakes in New South Wales. These include Wallis Lake, Smiths Lake and Myall Lakes. Wallis Lake is a major oyster-producing area for the Sydney region. It also offers excellent recreational boating and fishing opportunities. Myall Lakes provides a unique national park camping experience, with kilometres of mirror-still, scenic waterways located next to, but a world away from, urban centres.

Newcastle is Australia's second largest city and a large commercial port, cur-

rently reinventing itself from a steel-making city to a cosmopolitan coastal metropolis. Port Stephens is renowned for its pearl white beaches and dolphin watching. The area offers spectacular coastal walks and off-road adventures over towering sand dunes at Stockton Beach.

Less than two hours north of Sydney, the Hunter region is noted for great wines, gourmet food, superb restaurants, cafes and bistros, rustic cottages set alongside the vineyards and beachside retreats.The Hunter Valley wine country is a popular destination for food and wine enthusiasts.

Tours of the wineries can be made by horse-drawn carriage, hot-air balloon or bicycle. The area is steeped in history including Maitland's elegant heritage precincts and Australia's oldest river port at Morpeth. Singleton and the Upper Hunter reflect Australia's rural and gold rush heritage and include a variety of small country towns and working farms.

Coastal development

Urban and industrial development has affected several estuaries here. Newcastle is Australia's largest coal export facility. The Hunter River, Wallis Lake and Camden Haven Estuary have well trained entrances with twin breakwaters. Local people debate over opening entrances of small coastal lakes like Lake Cathie.

North coast estuaries are popular for recreational boating, swimming and fishing and include significant areas of estuarine wetlands renowned for aquatic birds and other wildlife. Lake Innes is fully surrounded by a national park.

The estuaries support a commercial fishing and prawn industry. Wallis Lake and Myall Lakes/Port Stephens have major fisheries including the highest catches of sand and dusky flathead in New South Wales. The Hunter also has important fisheries.

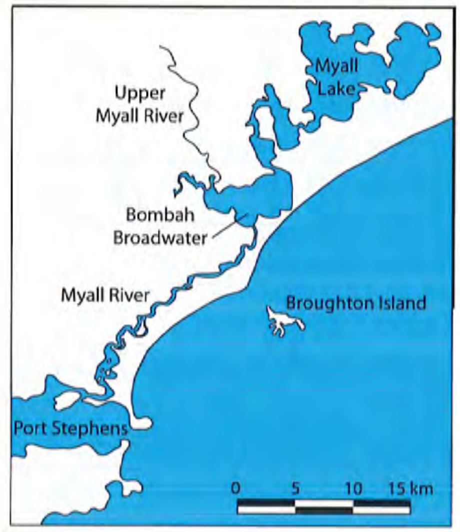
Several estuaries are intensive oyster producers. On occasion, faecal contamination from overloaded septic systems, public toilets and stormwater has led to shellfish closures in the region.

The Hunter has been extensively modified by industry at the mouth and by catchment land use. The valley is a major centre of coal mining, electricity generation, agriculture, aquaculture and tourism. There are several dams in the catchment, which supports intense and varied land use and commercial activities, many of which reduce water quality downstream, and affect habitat and water availability for native fauna and flora.

Hot air ballooning over vineyards (above); harvesting grapes (facing page); the Brokenback Range (left), photos courtesy Hunter Valley Wine Country

Wallis Lake, showing twin training walls at the entrance

Case study: Myall River and Lakes



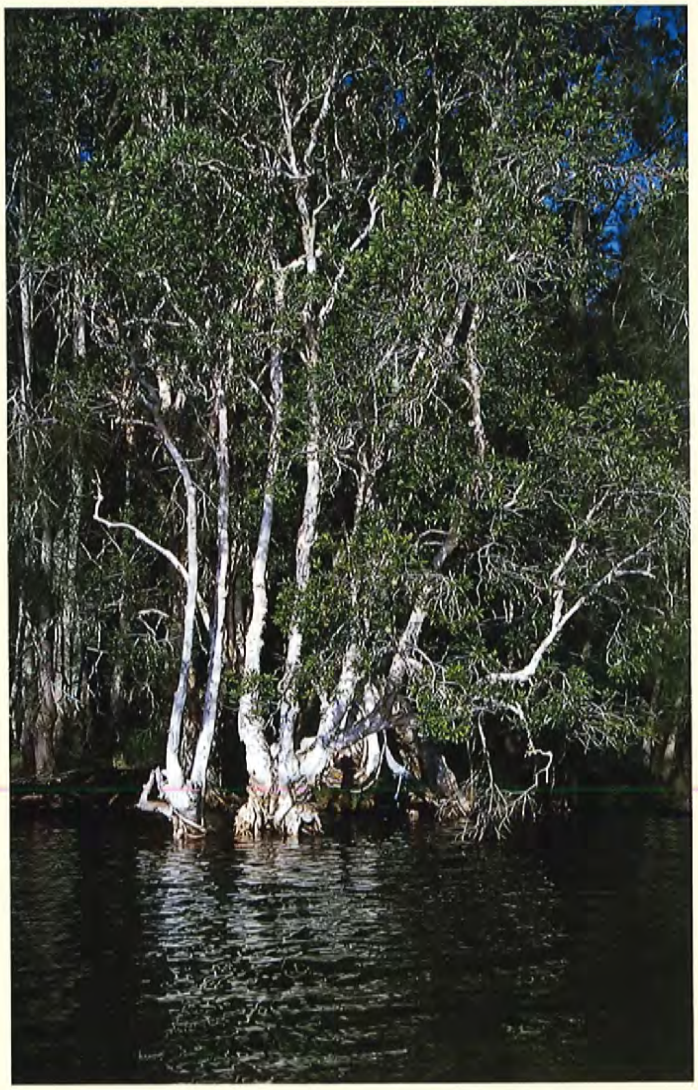
The Myall estuary is a diverse system of coastal waterways (the Myall Lakes) connected to Port Stephens by the Myall River. The Lakes are the largest fresh/brackish lake system in New South Wales. They are a good example of the complex systems that occur along the central and lower north coast of New South Wales. Most of the upper lakes are virtually fresh with little estuarine vegetation, but in the Myall River, salinity is close to that of seawater. Salty water moves up into the Bombah Broadwater during extended dry periods. Shallow areas, seagrass and other aquatic plants provide feeding and breeding areas for black swans and other waterbirds, and large areas of shoreline are fringed with eucalyptus/melaleuca wetlands.

Dolphins frequently visit the lower Myall River. The Lakes remain in relatively undeveloped condition, particularly the largest, Myall Lake. Historically, the area was heavily logged for red cedar, which was floated downriver and exported from Port Stephens. Sandmining began in the lakes in the 1960s but had ceased by the time the lakes were declared national park in 1972. Commercial prawning supports the small town of Tamboy, at the junction of the Myall River and Bombah Broadwater. Prawns are caught at night in the upper Myall River and Broadwater, with the prawn run peaking around February.

A number of threats to the lakes stem from their popularity for recreation. Impacts of high-density camping and vehicle access to sensitive areas include loss of vegetation and shore erosion. The Broadwater is a popular area for power boating and water-skiing.

While three-quarters of the catchment remains forested, the lakes have begun to exhibit some signs of eutrophication. As a result of poor tidal flushing, nutrients in agricultural run-off accumulate in the lakes and promote the growth of algae. Blue-green algal blooms in 1999 and 2000 directly affected the local fishing and tourism industries. The Broadwater occasionally smells when aquatic vegetation, chopped by either wave action or swan feeding, washes up and rots on the shore.

Myall Lakes (left); Myall Lake, Bungwahl (facing page and below)



The character of the upper Myall Lake is very different to that of the Broadwater. It receives less catchment run-off and is more typical of a freshwater lake with low salinity, clear water and freshwater algae including non-harmful blue-green species. Within the upper Myall Lake, nutrients are recycled through regular boom–bust cycles of certain types of aquatic plants, which become very dense during warmer brighter months. These plants die off rapidly when cooler conditions arrive. The upper Myall also has a benthic algal mat (up to 75 cm thick), dominated by a blue-green algal species unique to the system. Research into the properties and significance of this mat is underway.

Results of preliminary scientific studies have suggested that denitrification, the natural process by which nitrogen is removed from the system, is low in the muddy sediments of the Broadwater.

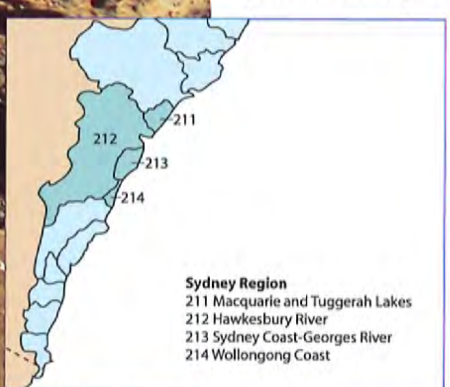
Sydney Region

Drowned river valleys and coastal lagoons

The wider Sydney region includes the estuaries from Lake Macquarie south to the Minnamurra River near Wollongong. Estuaries at the edges of the region are predominantly wave-dominated. Towards the centre are several drowned river valleys with large estuarine waterways. Sydney itself is situated in a broad coastal basin stretching back some 20 to 30 km to the Great Divide. Rainfall over this area is patchy varying from about 1200 mm in coastal areas to about 600 mm in the far western suburbs. It is relatively uniform year round, though the January to June period is slightly wetter.

To the south, the Illawarra region has a physical setting very different to that of Sydney. Here, a narrow coastal plain (only 1–8 km wide) separates the coast from a steep escarpment to the west. The climate is relatively mild and consistent, with rainfall on the coast of about 1200-1300 mm. This increases in the ranges, which support pockets of temperate rainforest.

Most estuaries in the Sydney region have patches of seagrass. The most extensive beds are found in Lake Macquarie and the Tuggerah Lakes. Just two mangrove species occur in the region, the river mangrove (*Aegiceras*) and the grey mangrove (*Avicennia*). Mangroves are found in some of the larger estuaries, the Hawkesbury River having the third largest stands in New South Wales. Saltmarsh, present in several estuaries, has been cleared from many others by urban development. Swamp forests, with broad-leafed paperbark (*Melaleuca quinquenervia*) and swamp she-oak (*Casuarina glauca*) dominating, form extensive fringing wetlands in the fresher parts of coastal lake systems such as Tuggerah Lakes and also occur as stands adjoining saltmarsh areas in several estuaries.



Brooklyn, Sydney Harbour

Australia's population centre

The Sydney region is Australia's population centre. Sydney, the largest city in Australia, is flanked by regional centres such as Wyong and Gosford to the north and Wollongong to the south. Wollongong is the major urban centre of the Illawarra region south of Sydney and the third largest city in New South Wales. This city grew as an industrial and commercial centre based around the local coal-mining industry and the large BHP steelworks. Tourism is a growing industry and Lake Illawarra is a popular destination for recreational activities such as sailing, prawning, fishing, water-skiing, cruises and canoeing.

Urban commerce, recreation and institutions

Estuaries in the Sydney region are affected by intense urban development, competing uses for natural resources, commercial ports and infrastructure and ocean sewage discharges (especially Sydney). These influences have degraded the water quality of estuaries and caused eutrophication in coastal lakes. After storms, beaches are in a poor state for swimming due to pollution and litter. Waterways exhibit localised pollution from sewage, industrial discharges and boat anti-fouling treatments. Pollutants include heavy metal, tributyltin, organochlorines, petroleum and micro-organisms. Tributyltin concentrations in Sydney Harbour and the Georges River are highest in areas of high boating activity such as Garden Island and Rushcutters Bay. High nutrient loads in run-off sometimes result in algal blooms.

Some of the larger coastal lakes such as Lake Macquarie and Tuggerah Lakes have been severely degraded. Lake Macquarie was the subject of a Premier's Task Force to address degradation and to begin rehabilitation. Wyong Shire Council has undertaken rehabilitation works on Tuggerah Lakes. There is intense urban and industrial development at Gosford, Wyong, the Sydney Metropolitan area and Wollongong. Coastal lagoon ecosystems are threatened by nutrients in urban run-off.

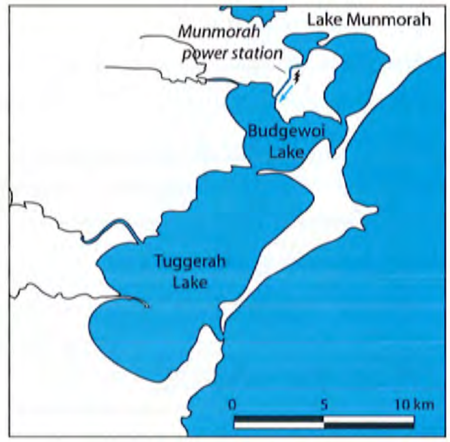
Port Kembla, Botany Bay and Sydney Harbour are commercial ports. Significant areas of coastal wetlands have been lost in the past to provide land for expanding urban and industrial development. Estuaries in the Sydney region are important holiday and recreational destinations for the city population with many camping and caravan reserves providing holiday and semi-permanent accommodation for visitors to the area. The estuaries are popular for amenity values, recreational fishing, boating, water-skiing and swimming.

The Hawkesbury River, Tuggerah Lakes, Botany Bay, Lake Macquarie and Lake Illawarra support a large estuarine fishing industry and commercial catches of crustaceans and molluscs. Oyster growing was a major industry in the Georges River although it has been set back by viral infection. Stocks in the Hawkesbury River are so far little affected. Exotic aquatic weed infestation is threatening a number of estuaries in this region.

Smog haze over Wollongong (below)

Case study: Tuggerah Lakes

Tuggerah Lakes, some 100 km north of Sydney, is a popular recreational area for the people of Sydney and Newcastle. It is also an important feeding ground and habitat for many aquatic birds. It has the fourth largest area of estuarine seagrass beds in New South Wales (11 km^2). The estuary consists of three shallow interconnected lakes, Lake Munmorah, Budgewoi Lake and Tuggerah Lake with a single entrance to the ocean from the largest of the lakes (Tuggerah). In its natural state this entrance was often closed by a sandbar. The lake shores underwent rapid urban growth in the 1960s and 1970s with most of the developing areas relying on septic treatment of wastes. Inputs of nutrients from local surface run-off and local groundwater led to persistent problems with eutrophication in the nearshore zone of the lakes. There was massive growth of seaweed (macroalgae) in these areas from the early 1980s.



Steps were taken to reduce nutrient loads entering the lakes and to combat the direct symptoms of eutrophication. These included the construction of a reticulated sewerage system during the 1980s and dredging of the entrance to improve tidal flushing. A foreshore reclamation project involved removing nearshore anoxic sediments, nutrients and macroalgae and constructing pollutant

traps and mini-wetlands on many stormwater drains discharging to the lakes. The abundance of seaweed declined. This result could be attributed to any or all of the actions taken or it may be related to a natural biological cycle. Even if nutrient inputs to the lakes ceased overnight, nutrient enrichment of the lakes would remain a persistent problem for some years because of the way the lakes act as a sink for sediments and nutrients, which are then released back into the water column over time.

Run-off from streams in the wider catchment tends to bypass the nearshore zones and supports phytoplankton populations in the main water bodies of the lakes. An increased nutrient load from future development in the wider catchment thus has the potential to trigger phytoplankton blooms in the lakes. The Munmorah Power Station, which takes water from Lake Munmorah and discharges heated water into Budgewoi Lake, may affect biological communities in the vicinity of the discharge zone. The power station has also been associated with a buildup of selenium in the lake sediments.

Munmorah Power Station takes water from Lake Munmorah and discharges heated water into Budgewoi Lake (above); urban development on Tuggerah Lakes entrance (facing page)

Annual rainfall is around 1250 mm per year. Rain is the major contributor to lake water level

Grazing in the catchment contributes to increased sediment and nutrient loads

Forestry in catchment

The lakes are surrounded by urban areas

Rivers and creeks in the wider catchment provide the dominant inputs to the main water bodies

Immediate catchment run-off and groundwater dominate nearshore zone inputs

Nutrients are stored in the sediment and released over time

Munmorah Power Station discharges water from Lake Munmorah into Lake Budgewoi

Thermal discharges from the power station

Selenium is found in sediments near the power station

11.6 km² of seagrasses (*Ruppia*, *Zostera*, *Halophila*) occur in the nearshore zone, forming an important feeding ground for waterbirds

Macroalgae dominated in the nearshore zone from the early 1980s before a sharp decline in 1992

Commercial fish and prawn producing estuary

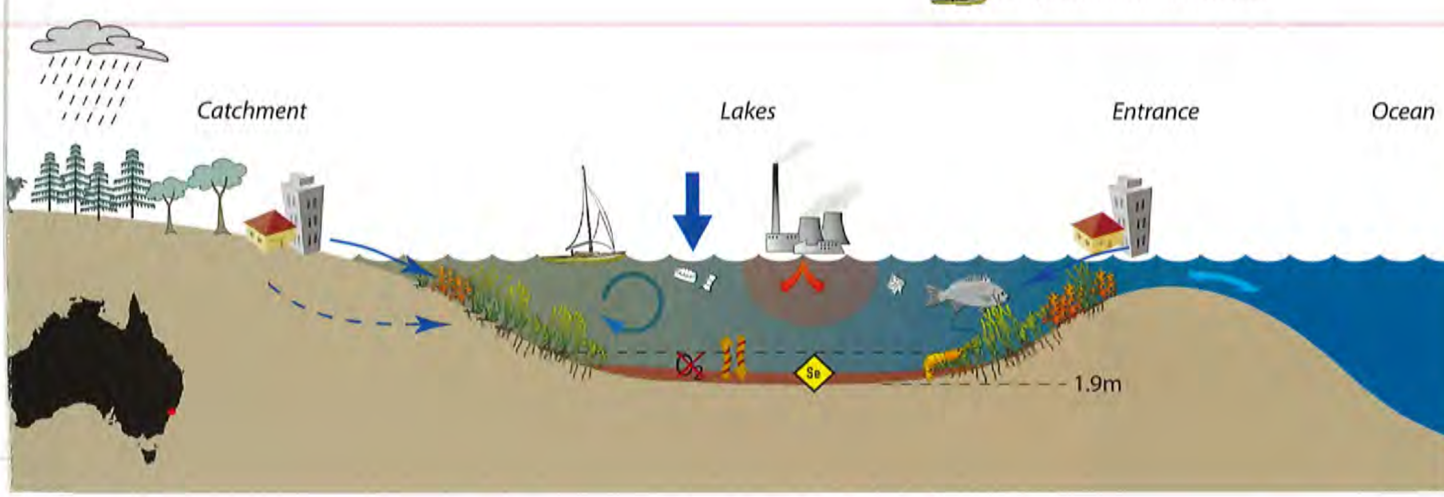
Phytoplankton dominate the main water bodies and may bloom in response to nutrients and/or reduced suspended sediments (i.e. increased light)

The lakes are usually well mixed by wind

Tidal flushing of Tuggerah Lake occurs through the entrance which undergoes periodic dredging

Periodic anoxia of bottom waters and sediment is associated with stratification events and may result in increased nutrient release into the water column from the sediments

Recreational boating impacts include litter and wash, which contributes to bank erosion



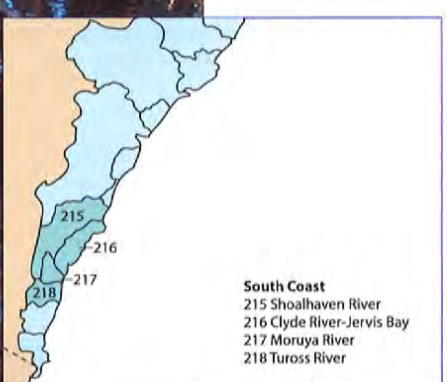
NSW South Coast

Scenic coastal lagoons with small, intact catchments

South coast estuaries extend along a wave-dominated coast, from Werri Lagoon south of Wollongong to Tuross Lake near Narooma. Estuaries drain small catchments along a narrow, hilly shore. Shoalhaven River is the largest in the region. Catchments are more intact than those nearer Sydney. Rainfall is 1000 to 1200 mm, more seasonal than on the far south coast and wettest from January to June. Some south coast estuaries have mangroves and many have saltmarsh. Two mangrove species occur here, the river mangrove (*Aegiceras*) and the grey mangrove (*Avicennia*). Seagrass is found in most estuaries with significant areas in Jervis Bay and St George's basin. Estuaries such as the Tuross River have a variety of environments including mangroves, saltmarsh and *Casuarina* swamp forest. Sand and mudflats provide habitat for migratory waders and other birds.

Defense and weekends

Kiama, south of Wollongong, attracts visitors from round the world to the famous blowhole and contrasts of rugged coast, rolling hills and lush rainforest.



The 10 national parks in the area have many unique features – world's whitest sand, unblemished shingle beaches and rugged headlands.

Jervis Bay is four times the area of Sydney Harbour. The area is known for dolphin watching. Bushwalkers encounter a wide variety of wildlife. The naval base in the bay has influenced development with attractions that include the Naval Aviation Museum and vintage air shows.

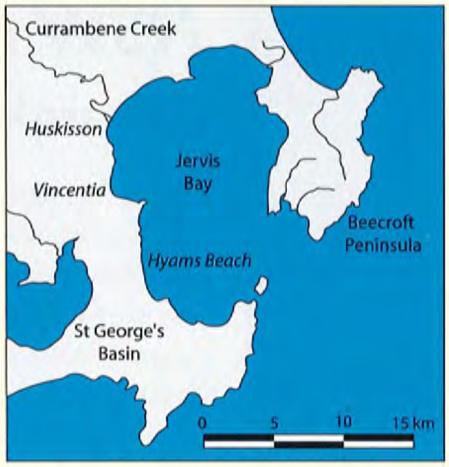
Angling is popular in the area. As well, the south coast has a unique cultural atmosphere. Historical coastal townships have art and craft galleries and shops selling local produce such as gourmet wines and cheeses.

Sleepy coastal lakes and secluded beaches are found between the townships of Bateman's Bay, Moruya and Narooma. Bateman's Bay is a popular holiday destination for visitors from Canberra. A large marina caters for popular deep-sea fishing charters and competitions.

Playground discovered – weekender tourism

Important issues facing managers of south coast estuaries include coastal strip development and competing natural resource uses, ports, marinas and tourist development, eutrophication of coastal lakes and the protection of Aboriginal fishing rights. It is a popular tourist destination for residents from Canberra and Victoria. Increased development pressures in the catchments of vulnerable small coastal lagoons have generated intense local debate and a call for improved planning practices.

Case study: Jervis Bay



Jervis Bay, a deep and accessible marine embayment, is an unusual feature on the New South Wales south coast where most water bodies have heavily shoaled entrances. Geologically it is unique. The bay formed when a broad downward warp in the Earth's crust flooded after the last ice age. The bay is protected by Beecroft Peninsula to the north and Cape St George to the south. It receives freshwater from many small creeks, the largest being Currambene Creek entering at the town of Huskisson. Several small towns (Callala Bay, Callala Beach, Huskisson and Vincentia) are located along the western shoreline. Jervis Bay is renowned for crystal clear water and long white beaches along a largely undeveloped foreshore. Recreational activities are popular, including scuba diving, swimming, surfing, boating and fishing. Jervis Bay is an overlap zone for warm temperate and cool temperate species. It supports an extremely rich marine flora and fauna, including about 200 species of fish, diverse invertebrates and 'charismatic' species such as weedy sea-dragons, seahorses, stingrays and dolphins, as well as visiting whales and seals. About 9 km^2 of seagrass beds exist in the bay. All seagrass species of New South Wales are found here. The bay supports the largest beds of the seagrass *Posidonia australis* in New South Wales, and mangrove, saltmarsh and vast freshwater wetland communities around the tributary creeks.

There is concern about urban and development impacts on water quality in Currambene Creek, though monitoring indicates it remains generally high. Jervis Bay was gazetted a Marine Park in January 1998, and is jointly managed by the National Parks and Wildlife Service and New South Wales Fisheries on behalf of the Marine Parks Authority. The Royal Australian Navy also uses the bay for training activities.

For thousands of years Aboriginal people have lived and fished in the bay. Local Indigenous communities are keen to maintain access to traditional areas. Booderee National Park and Booderee Botanic Gardens are the names chosen by the Wreck Bay Aboriginal Community for the former Commonwealth Jervis Bay National Park and Jervis Bay Botanic Gardens. The park and gardens were handed back to the Wreck Bay Aboriginal Community in 1995. The Community and the Commonwealth Government, through the Director of National Parks, now jointly manage them.

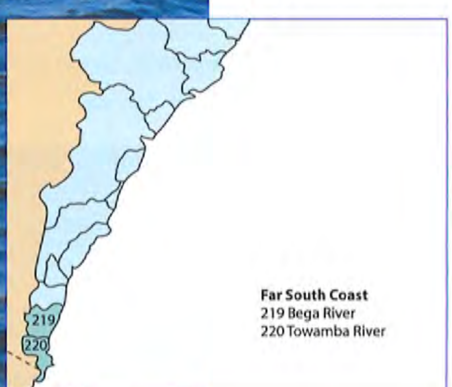
Significant sites with evidence of Indigenous occupation such as middens, ceremonial grounds, rock art and various tools are dotted around the shoreline of the bay.

NSW Far South Coast

Lakes and lagoons

The far south coast Region includes the estuaries from Lake Brunderee (near Potato Point) south to Nadgee Lake near the Victorian border. Most of the estuaries in this area are small and wave-dominated. The one estuary draining a larger valley is the Bega River. It receives high river energy from the catchment during floods but is nevertheless wave-dominated and has a heavily shoaled entrance. Twofold Bay is a deep, open, marine embayment with some smaller estuaries draining into it. Rainfall is slightly lower than in the south coast region, averaging 800 to 1000 mm, and is distributed relatively evenly throughout the year. Catchments in this region are relatively short and steep and many remain well forested. Some are completely protected within reserves.

Mangroves are found in some of these estuaries, generally only the grey mangrove, however the river mangrove *(Aegiceras)* occurs in Nelson Lagoon and Merimbula Lake. Areas of saltmarsh and small patches of seagrass are found in most of the estuaries of the far south coast. Kelp forests occur around rocky foreshores of Twofold Bay. The bay is home to several threatened sea-birds and a rest area for migrating whales including humpback, southern right and blue whales.



Parks and reserves

The protected areas in southeastern New South Wales draw visitors from around the world to some of the most pristine and spectacular sections of coastline in southern Australia. In addition to a number of significant inland national parks are coastal reserves including the Wallaga Lake, Mimosa Rocks, Bournda, and Ben Boyd national parks, and the Nadgee Nature Reserve. The latter, adjoining Victoria's Croajingolong National Park, contains the only coastal wilderness in New South Wales and represents one of the largest undeveloped catchments on the eastern seaboard. The catchments of the Merrica River, Little River, and Nadgee River estuaries and Nadgee Lake are entirely protected within this reserve. Visitors can experience unique coastal walks along the rugged and beautiful coastline including sandy beaches, rocky headlands and spectacular flowering heaths and *Banksia* forest. The wealth of recreational opportunities offered by these parks includes hiking, picnicking, swimming, beach fishing, surfing, snorkelling and birdwatching.

Discovering the playground

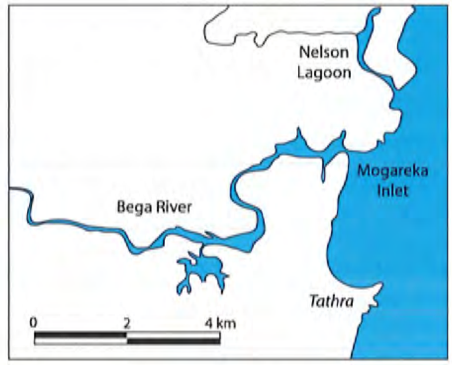
Coastal development on the far south coast is limited compared with other parts of New South Wales. Several of the upper catchments are rural, including dairying areas such as the Bega valley. Twofold Bay supports an important commercial fishery that includes blue mackerel, Australia salmon, pilchard and silver trevally. Many estuaries in the region are surrounded by large expanses of national park, and most coastal lakes and lagoons have limited public access compared to other areas of the state. The outstanding natural features of the region are central to a burgeoning tourist economy. The large fishing ports of Bermagui and Eden are popular holiday destinations, and the uncrowded beaches, coastal lakes and rivers, rainforest and other old-growth forests, whale watching, wildlife and fishing are popular attractions. Ensuring that future tourism development is compatible with environmental values is a critical issue for communities and managers in the region.

The Merrica River and catchment are entirely protected within the Nadgee Nature Reserve. (facing page)

The Bega River enters the ocean through the heavily shoaled channel known as Mogareka Inlet.

Case study: Bega River

The Bega River estuary enters the ocean through the heavily shoaled entrance channel known as Mogareka Inlet approximately 3 km north of the tourist town of Tathra. The estuary is very beautiful and is a popular fishing spot, particularly for mulloway, bream and flathead. The lower estuary is also a popular recreational area for boating, water-skiing and sailboarding.



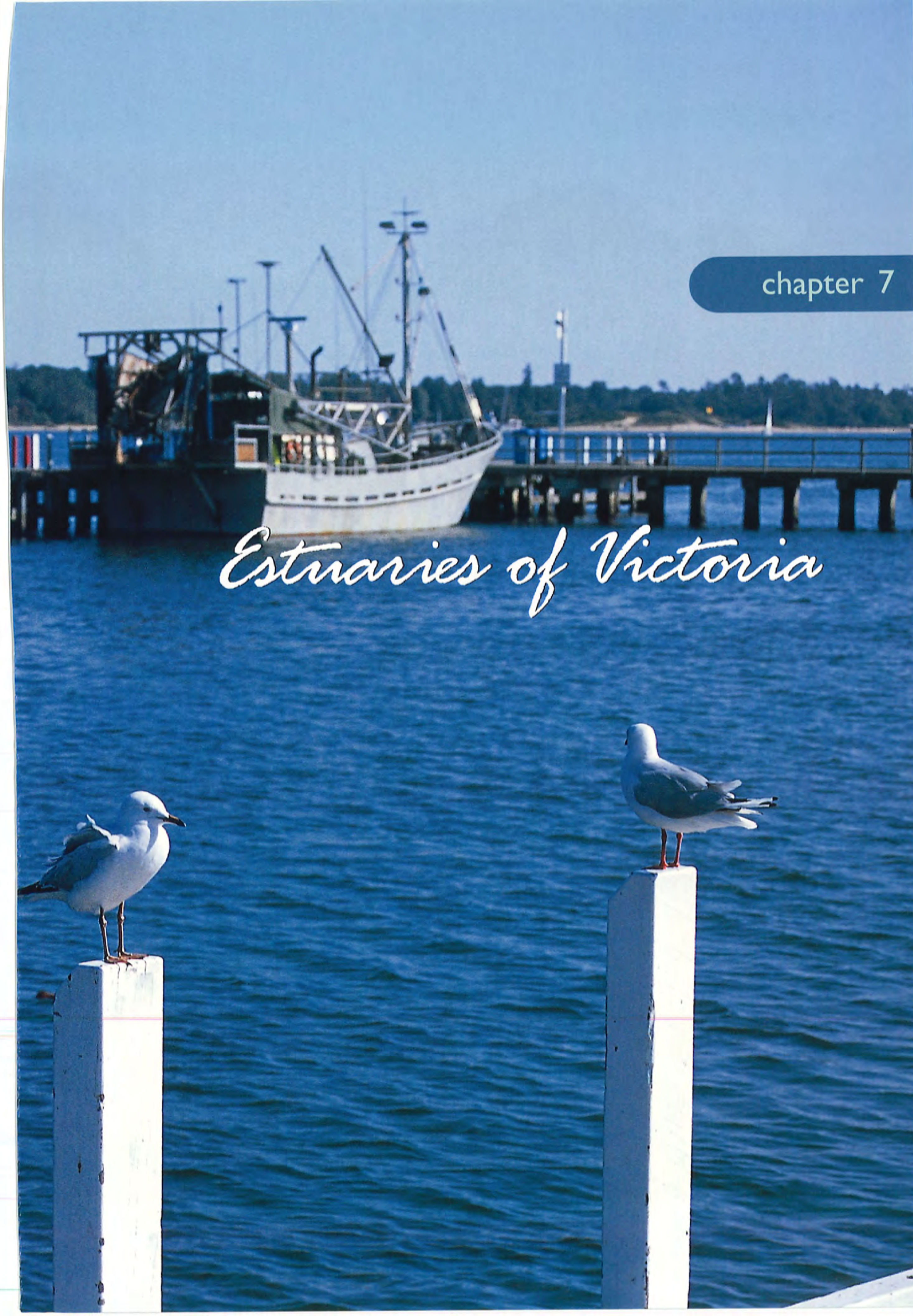
First explored by Europeans when George Bass sailed the length of the estuary in 1797, the Bega River is the major river system in the far south coast region of New South Wales. The tidal reaches of the river extend upstream about 11 km near to the junction of Jellat Jellat Creek. Upstream from the town of Bega, the river splits into two major tributaries, the Bemboka and Brogo rivers. The upper catchments flow through the heavily forested Brogo Ranges. Wetland areas in the catchment, which were historically important for maintaining flow in the river during low rainfall periods, have been significantly degraded. Flow to the estuary has also been heavily regulated by the operations of two dams, the Cochrane Dam on the Bemboka River, which generates hydroelectric power and Brogo Dam on the Brogo River, which supplies irrigation water to farms in the catchment. About half the catchment area was cleared for agriculture in the 19th century. The Bega valley still supports an important dairying industry, much of which is based on irrigated pastures. Unlike most other rivers on the far south coast, the Bega River transports sediment all the way to the ocean during floods, which can be severe. Water regulation and erosion in the catchment, particularly from the Wollumla subcatchment, has led to problems with sedimentation in the estuary and in the lower freshwater reaches of the river.

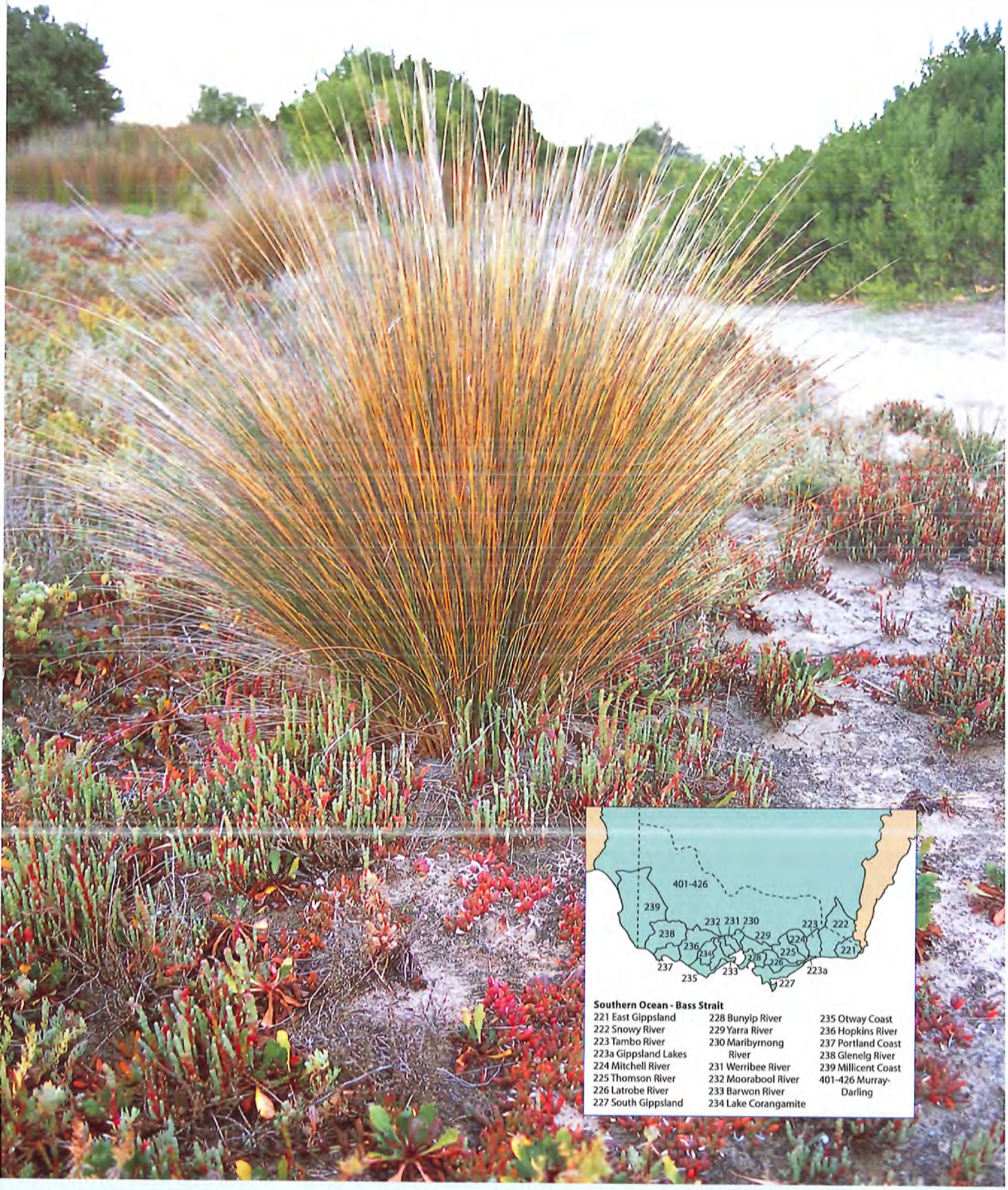
Mogareka Inlet at the mouth of the Bega River

Estuary management in New South Wales	
Management arrangements	The New South Wales Coastal Policy and Coastal Zone Management Manual provides the framework and management process to assist local communities to sustainably manage the state's estuaries.
Key issues	• need for a fully integrated approach involving federal, state, and local Governments, industry and the community to provide best outcomes and efficient use of available resources • address estuarine water quality and sedimentation • reduce degradation and loss of estuarine habitats from development pressures • protection and rehabilitation of remaining coastal wetlands • improve sustainable use of estuarine resources • increasing demand on available environmental flows from catchments into estuaries • protecting the ecological sustainability of streams and creeks flowing to estuaries (particularly urban catchments) • need for long-term strategic research and monitoring of estuarine environments • improve strategic planning in estuarine and coastal environments • management of intermittently closed and open lakes and lagoons (ICOLLs) • management of acid sulfate soils to reduce fish kills and retain agricultural productivity • management of toxic algal blooms • control of exotic aquatic flora and fauna
Key management responsibility	Key state agencies involved in the management of estuaries include the: • **Department of Infrastructure Planning and Natural Resources** – land, water and vegetation natural resource management, state planning development policies • **Department of Environment and Conservation** – environmental pollution control and managing national parks and reserves • **New South Wales Fisheries** – managing State fisheries resources • **Waterways Authority** – managing boating and navigation • **Department of Lands** – managing Crown lands
Policy and legislation	The **New South Wales Coastal Policy** provides the key strategic direction for the sustainable management of the New South Wales coastal zone. Estuary plans may be gazetted under the *Coastal Protection Amendment Act 2002*. Implementation of the policy and achievement of its outcomes are assessed by the **Natural Resources Commission of New South Wales**. The **New South Wales Estuary Management Policy**, a key deliverable of the New South Wales Coastal Policy, is implemented through the preparation and implementation of sustainable estuary management plans involving significant community consultation through a partnership with local councils. Other legislation relevant to estuary and catchment management includes the *Natural Resources Commission Act 2003; Coastal Protection Amendment Act 2002, Water Management Act 2000; Vegetation Management Act 1999; Catchment Management Act 1989; Wetlands Management Policy 1996; Fisheries Management Act 1994* and the *Crown Lands Act 1989.*
Community initiatives	• Include **Coastcare**, **Streamwatch**, **Landcare** and **Rivercare** • The community has a vested interest in its estuaries via representation on a number of natural resource management committees supported by the state government including catchment management authorities (regional strategies and investment) and coastal zone management committees (local coast councils)

chapter 7

Estuaries of Victoria

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Southern Ocean - Bass Strait
221 East Gippsland
222 Snowy River
223 Tambo River
223a Gippsland Lakes
224 Mitchell River
225 Thomson River
226 Latrobe River
227 South Gippsland
228 Bunyip River
229 Yarra River
230 Maribyrnong River
231 Werribee River
232 Moorabool River
233 Barwon River
234 Lake Corangamite
235 Otway Coast
236 Hopkins River
237 Portland Coast
238 Glenelg River
239 Millicent Coast
401-426 Murray-Darling

Strung along the Victorian coast are more than 60 estuaries. Their impressive diversity includes small wave- and river-dominated estuaries in the west, the large embayments of Port Phillip Bay and Western Port in central Victoria, the extensive Gippsland Lakes system and a network of small wave-dominated estuaries in the east. Variations in the condition of the estuaries is mostly due to differences in the size and form of the surrounding catchment as well as the dominant land use practices.

Eastern Victoria's estuaries are predominantly located in national parks and are near-pristine making them valuable conservation and wilderness areas. The small wave-dominated estuaries common in western Victoria are at risk from inappropriate land use practices and in need of targeted management. Many have only occasional openings to the coast and much of the adjacent catchment is steep and agricultural. Nutrients, sediment and toxic substances can accumulate in such estuaries. Urbanisation, industry, agriculture and forestry in adjacent catchments, along with water diversions and extraction have resulted in major modifications to many individual estuaries throughout Victoria. The main agricultural industries on Victoria's coastal fringe are cattle and sheep production. As well, there is some cropping and market gardening.

The importance of estuaries is now well recognised in Victoria, both at government and community levels. Pressures on estuaries are expected to increase as coastal development continues. Environmental objectives for estuaries are now explicitly recognised in key policies and management plans and are undergoing further development. A coordinated approach is being taken on catchment and coastal management strategies, research and monitoring. Access to information and resources for community groups who monitor and care for estuaries is being improved. Large estuarine systems in Victoria are relatively well understood and monitored compared to the small estuaries, which require greater attention.

Regions

- *Eastern Victoria*

  (from Mallacoota Inlet to Andersons Inlet)

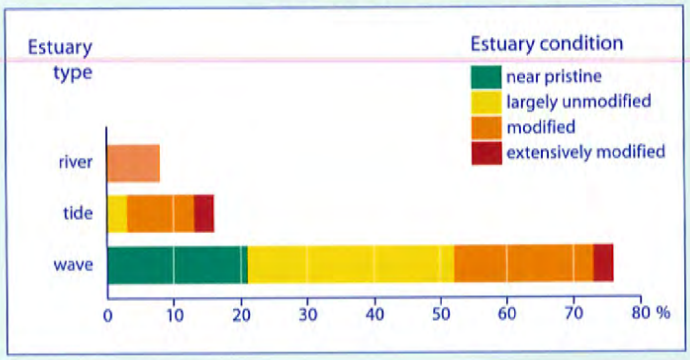
- *Port Phillip Bay & Western Port*

  (from Powlett River to Barwon River)

- *Western Victoria*

  (from Thompson Creek to Glenelg River)

Estuaries of Victoria – type and condition



Eastern Victoria

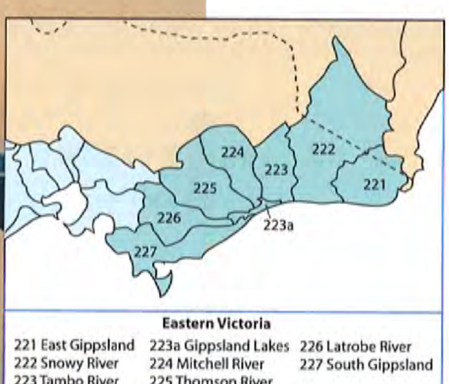
Snowy Mountains, coastal lagoons

In the southeast of Victoria, the rivers which head from the northern slope bear a strong general resemblance to each other. They take their rise in the mysterious recesses of mountains so thickly clothed with timber and so inaccessible that the sanctuaries of Nature have remained for centuries unprofaned by human foot…

The Picturesque Atlas of Australasia, 1886

With the exception of Corner Inlet, the estuaries from Andersons Inlet to Mallacoota Inlet in the far east of Victoria are wave-dominated. They are found along a moderate-energy coast, dominated by vegetated bluffs and long sandy beaches. Wilson's Promontory dampens the southwesterly ocean swell. The waves from the south and southeast are rarely as vigorous as those formed by swell from the Southern Ocean.

Average rainfall is fairly even throughout the year and comes both from westerly systems and rain depressions off the east coast. Rainfall varies greatly throughout the region, from over 2200 mm on the Errinundra Plateau to about 500 mm in rainshadow areas like the upper Snowy River valley. South Gippsland has the benefit of rainfall from the Strzelecki Ranges, while the Ninety Mile Beach (Gippsland Lakes) is in rainshadow and has low rainfall. Easterlies can bring heavy rain to the coast east of Lakes Entrance.



The upper catchments of rivers in this region rise in Victoria's high country. The Tambo, Mitchell, Thomson and Latrobe river basins all empty into the Gippsland Lakes. Further east, the Snowy River and several smaller catchments enter the Tasman Sea.

Habitats occurring in these estuaries include sandflats, mudflats and associated drainage channels, seagrass beds and mangroves. The region has the most southern occurrence of mangroves in the world in Corner Inlet. *Avicennia marina*, known locally as the white mangrove, is the only mangrove species in Victoria, and occurs as a stunted shrub. Mangroves are also found in Andersons Inlet. Significant beds of seagrass exist in a number of the estuaries, including *Posidonia australis* in Corner Inlet.

Victoria has introduced a network of marine parks. Some of these contain or overlap with estuaries along the Victorian coast. Some Ramsar sites are present in eastern Victoria.

Charlotte's Pass, Kosciuszko National Park

Water quantity and quality

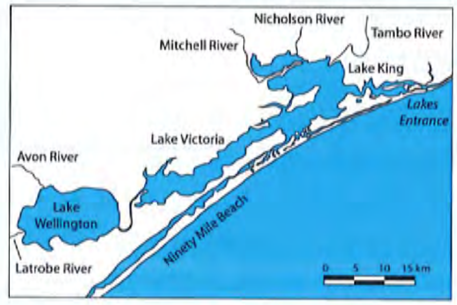
Eastern Victoria has the greatest proportion of near-pristine estuaries in the state. Croajingolong National Park in the state's far east provides some catchments with partial protection. Further west, land has been cleared for pasture and supports a number of small-to-medium regional centres. The Gippsland Lakes are a focus for tourism and commercial and recreational fishing. Gippsland Lakes have been degraded as a result of both catchment-derived inputs of sediment and nutrients (particularly from the Latrobe River) and coastal infrastructure development. Further westwards towards Sale, grazing of both dairy and beef cattle is extensive. Dairying dominates the south Gippsland area.

In central Gippsland, the Latrobe Valley is an important agricultural area, but also has large resources of brown coal and a number of associated power stations. Reduced flows to several estuaries have resulted from water extraction upstream (e.g. the Snowy River). The many wave-dominated estuaries in this region are susceptible to increased nutrient loads resulting from agricultural activity in the adjacent catchments. The exotic grass *Spartina* is a problem in parts of south Gippsland, particularly Andersons Inlet at Inverloch. Corner Inlet is another area of fluctuating seagrass condition. Where declines have occurred, they may be related to run-off from agricultural land, dredging or boating activities. Seagrass loss may have contributed to a significant decline in commercial fish catches during the 1970s. Commercial fishing occurs in several estuaries: Corner Inlet, Gippsland Lakes, Lake Tyers, Tamboon Inlet and Mallacoota Inlet. Two estuaries, Shallow Inlet and Anderson Inlet, have not been commercially fished since a voluntary licence buy-back in 1999.

Commercial fishers at Lakes Entrance, Gippsland Lakes (below);

Early morning at low tide, Andersons Inlet, Inverloch (bottom)

Case study: Gippsland Lakes



Gippsland Lakes is one of Australia's largest coastal lagoon systems (400 km^2). Various freshwater and brackish wetlands and submerged aquatic plants, such as seagrass, provide habitat for numerous fish and bird species, including pelicans, black swans and herons. The lakes are very popular for recreational boating and tourism. Commercial fishing is also important. Commercial species include black bream, yellow-eye mullet and Australian salmon. The top species caught by weight is European carp. This introduced species feeds in bottom sediments, resuspending mud into the water-column and damaging benthic habitats. Wind mixing of the shallow Lake Wellington also resuspends sediments and muddies the water.

Historically this was an intermittently open system of brackish lakes. The creation of a permanent entrance at Lakes Entrance in 1889 increased salinity, particularly in the lower lakes, and reduced average water levels and annual water level fluctuations within the lakes. A relatively sharp distinction now exists between low salinity levels (less than five parts per thousand) in the upper Lake Wellington and the much saltier lower lakes including Lake Victoria and Lake King. These lower lakes stratify during periods of high freshwater flow.

All of these changes have placed stresses on the lakes' ecosystem. Increased salinity is leading to loss of freshwater reed beds and melaleuca swamps and expansion of mangrove areas, which are intruding into areas of saltmarsh. Clearing of the formerly heavily forested catchment for irrigated agriculture and grazing has greatly increased the nutrient and sediment loads deposited in the lakes.

Large areas of the catchment are also devoted to forestry. The Latrobe, Macalister and Thomson rivers flow to Lake Wellington and have been dammed for water storage. An urban population of 130,000 and industries (including a coal-fired power station and a paper mill) are located along the Latrobe River. Prior to their diversion, industrial and sewage effluent were discharged into the Latrobe River for over 50 years. Large areas of the catchment are also devoted to forestry.

These changes in the catchment have lead to degradation of the lakes. Water quality is poorest in Lake Wellington, largely as a result of sediment and nutrient inputs from

Gippsland Lakes, aerial view

the Latrobe River. The northern arm of Lake King is affected to a greater extent than the rest of the lower lakes as a result of flows from the Mitchell River catchment. The lakes act as a sink for various catchment inputs, including sediments and nutrients. As well, mercury, which is thought to be a remnant of goldmining in the 19th century has accumulated here. Increased nutrient levels in the lakes has led to prolific growth of a number of aquatic plants that threaten the lakes' ecosystem. Phytoplankton bloom periodically (including toxic blue-green algae such as *Nodularia spumigena*), epiphytic algae choke seagrass by reducing light reaching the leaves and macroalgal populations have increased. These problems are difficult to control because nutrients are stored in the sediments and released over time. Bacteria use up oxygen in the water, and from time to time, lack of oxygen suffocates fish and other species. Recreational boating impacts include litter and wash, which contributes to bank slumping.

Winter rainfall, 660 mm/year

Cropping in the catchment has led to increased sediment and nutrient loads

Grazing in the catchment contributes to increased sediment and nutrient loads

Small townships are present in the catchment and adjacent to the lakes

The Latrobe catchment delivers high sediment and nutrient levels in run-off

Groundwater inputs may include dissolved salts due to rising water-table

Lakes receive freshwater inflows directly from their catchment

European carp disturb bottom sediments

Wind mixing of the water-column resuspends bottom sediments in Lake Wellington

Water clarity is very low in Lake Wellington and moderate in the lower lakes

Salinity is low (~5 ppt) in Lake Wellington

Strong vertical stratification occurs in the lower lakes especially in winter

Lake Wellington is possibly phosphorus limited

Lakes Victoria and King are nitrogen limited, but may be phophorus limited at times

Ammonia fluxes from sediments indicate poor ecosystem health

Mercury is present in the sediments

Entrance dredging has increased lakes' salinity

Tidal flushing occurs through the entrance

Increased salinity is leading to loss of reed beds and *Melaleuca* swamps

Oxygen is depleted in bottom waters and sediments of the lower lakes

Low-oxygen conditions cause fish deaths

Blooms of cyanobacteria occur in the lakes (*Nodularia* in the lower lakes)

Mangrove areas are encroaching on saltmarsh

Saltmarsh and saltpans are replacing freshwater marshes

Benthic microalgae abundant in lower lakes

Seagrass threatened by epiphytic algae growth

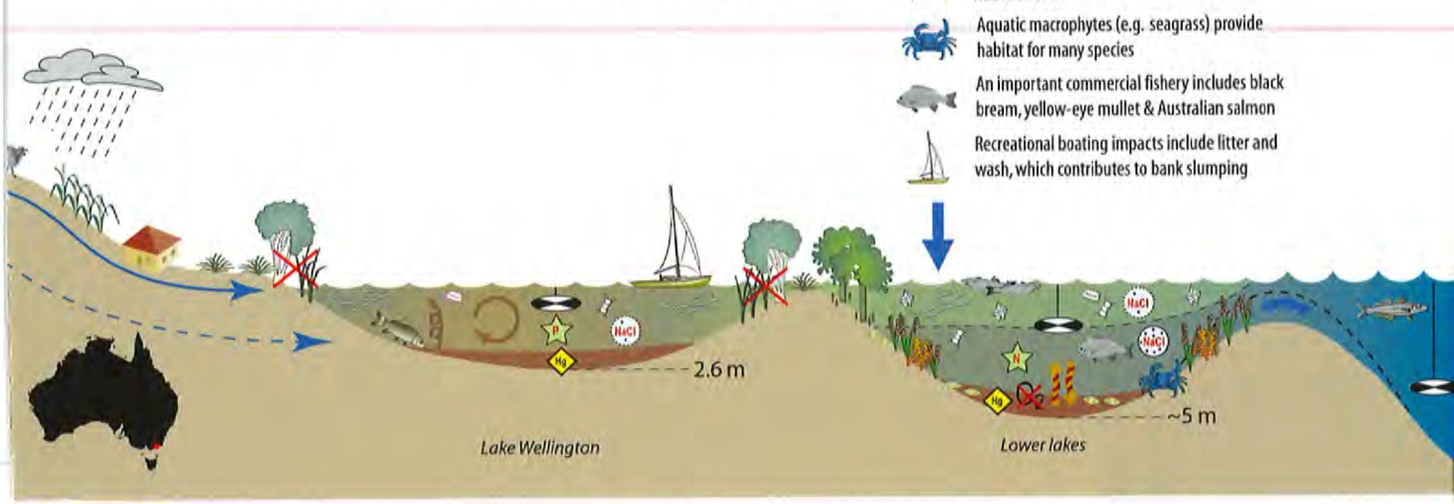
High nutrient levels lead to abundant growth of macroalgae in shallow areas

Phytoplankon bloom in response to elevated nutrient levels

Aquatic macrophytes (e.g. seagrass) provide habitat for many species

An important commercial fishery includes black bream, yellow-eye mullet & Australian salmon

Recreational boating impacts include litter and wash, which contributes to bank slumping

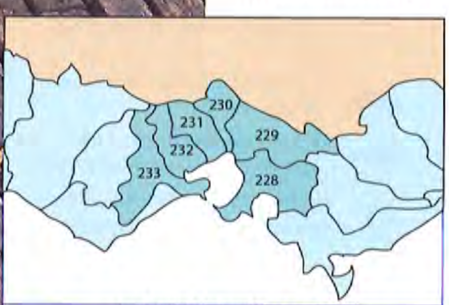


Port Phillip Bay & Western Port

Large, enclosed bays

Central Victoria is dominated by two large embayments, Port Phillip Bay and Western Port. Most other estuaries in this region are 'child' estuaries draining into Port Phillip Bay – the largest marine bay in Victoria, covering 1950 km^2 with a coastline of about 250 km. Western Port is smaller (680 km^2), but has greater wildlife diversity. These estuaries are protected from the Southern Ocean swells dominating most of Victoria's coast so they are tide- or river-dominated. Because prevailing westerlies generate waves within the bays, wave action is stronger on the eastern shores. The western shores are low energy coasts where deposits of sand and mud have created beaches, spits, saltmarshes and mangroves.

The western Port Phillip Bay catchment is in the rainshadow of the Otway ranges so has the lowest rainfall in the region. Rainfall is low to moderate, about 600 to 700 mm per year in the Port Phillip Bay area and higher in the Western Port catchment. Rain falls throughout the year but winter sees many more rain days. Tide range on the open coast is low, and is further reduced by the narrow entrance in Port Phillip Bay. In contrast, the tide range is higher in Western Port (up to 3 m) due to the funnelling effect of the narrow straits around French Island.



Port Phillip Bay and Western Port

233 Barwon River, 232 Moorabool River, 231 Werribee River, 230 Maribyrnong River, 229 Yarra River, 228 Bunyip River

Both Port Phillip Bay and Western Port show a wide range of marine and estuarine habitats with diverse biological communities. With its greater tide range, Western Port has an extensive intertidal zone, with seagrass beds, mangroves, saltmarshes, sandflats and mudflats. These important habitats for fish and migratory wading birds have been declared Ramsar sites. Both bays have large areas of seagrass, dominated by *Zostera muelleri* and *Heterozostera tasmanica*. Habitats in Port Phillip Bay range from a sandy sea floor along the eastern and southern sides of the bay to a large muddy central basin, intertidal flats and seagrass beds on the western shore. The entrance at Port Phillip Heads is more oceanic.

Marine national parks have been established. Four Ramsar sites are adjacent to Port Phillip Bay and one in Western Port.

The urban footprint

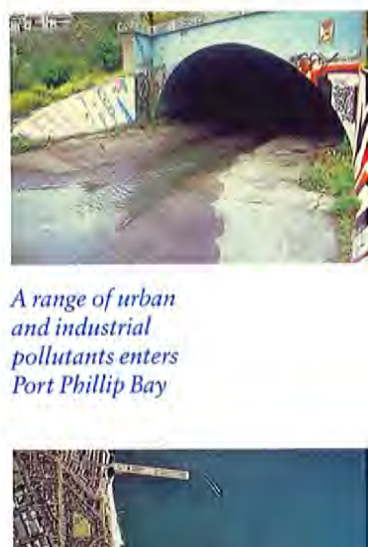
The region has a large, diverse human population. Landscape and local climate vary. This contributes to a variety of agricultural, urban and industrial land uses supporting a multicultural population. The Port Phillip Bay catchment is heavily urbanised, with Melbourne and Geelong accounting for about four million people. The Western Port catchment is more agricultural. A large proportion of Victoria's highly productive land is in this region. Capturing water for urban and agricultural use is a key planning priority for these catchments.

Despite large populations, the bays support a wide range of marine ecosystems in generally good condition. For now, the large size of the bays seems to have buffered them from severe problems encountered by estuaries near other major urban centres. However, both bays are under stress. Eutrophication, sedimentation, oil spills and the introduction of marine exotics are key threats to Port Phillip Bay and Western Port. Catchment erosion, resuspension of unconsolidated bay sediments and potential impacts from oil spills are key threats to Western Port and in part have contributed to large-scale seagrass decline in the bay. To maintain the environmental, recreational and economic values of the bays, the ecological footprint of a growing population must be reduced.

Melbourne's settlement, concentrated on the northern and eastern shores of Port Phillip Bay, sprawls southward along the coast. Geelong is centred on Corio Bay in the southwest. Several rivers and creeks running through urban and industrial areas have been turned into drains. All the estuaries are classified as modified, though Kororoit Creek flowing through industrial land is extensively modified. A range of urban and industrial pollutants enters the bay via streams such as the Yarra. Past industrial discharges, much more loosely regulated than at present, have caused high levels of toxic substances to accumulate in sediments at several sites in the bay. Port Phillip Bay also traps stormwater run-off, pollution from unsewered urban areas and run-off from other catchment activities. Programs and public education are reducing these inputs. About two-thirds of Melbourne's sewage is highly treated at the Western Treatment Plant and discharged to western Port Phillip Bay, an important Ramsar site. Algal blooms have occurred in the bay, particularly after summer rain.

Port Phillip Bay and Western Port are both major shipping ports, affected by dredging of channels, disposal of dredge spoils, use of anti-fouling paints, hydrocarbon spills, cleaning of fouled ship hulls and disposal of ballast water. Modifications for port development include construction of channels to improve navigation of the meandering Yarra River and the historical removal of submerged rocks at Port Phillip Heads. Hull fouling and ballast water discharge have introduced numerous species from foreign ports. More than 90 introduced animal and plant species have been detected in Port Phillip Bay, including declared pests.

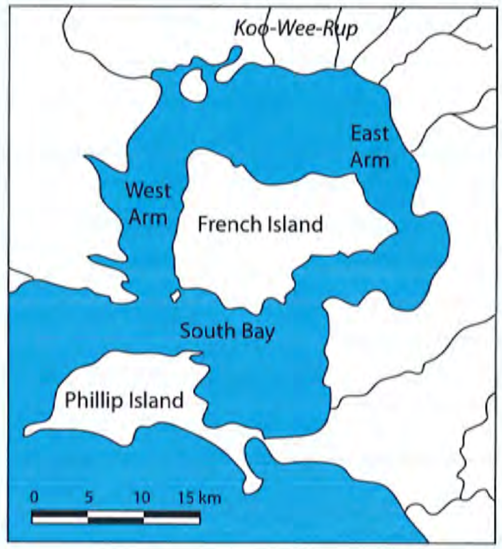
The bays also support fishing and aquaculture, currently centred on farming blue mussels. Port Phillip Bay is the most heavily fished of Victoria's bays and estuaries. Targeted species include snapper, King George whiting, flathead, calamari, garfish and yellow-eye mullet. Port Phillip Bay and Western Port include some of Victoria's most important coast for recreation and tourism. Boat ownership in Victoria has doubled in the last 20 years. Boats have caused erosion of the shoreline where access channels have been cut. This has contributed to a reduction in the mangrove fringe in Western Port. A growing ecotourism industry centres on abundant wildlife-watching opportunities, particularly in southern Port Phillip Bay. Both bays have been well studied and there is comprehensive data on the ecology, condition and functioning of these systems.



A range of urban and industrial pollutants enters Port Phillip Bay

Port Melbourne

Case study: Western Port



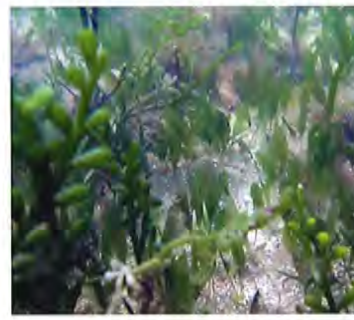
The large estuarine embayment of Western Port (680 km²) surrounds French Island, with Phillip Island located across the southern part of the entrance. Freshwater input is low relative to the volume of the bay and is mainly delivered by the Bunyip, Bass and Lang Lang rivers. The current population of the catchment is approximately 150,000 having increased from about 45,000 since the 1970s.

The Port of Hastings in the western bay receives the second smallest number of ship visits but a disproportionately large amount of ballast water, though at present there are few recorded exotic species. Hastings is the site of the first national project aimed at controlling the introduction of marine pests through ballast water control. Population pressures such as urban encroachment on habitat, stormwater run-off, and associated pressures from recreational use are increasing.

This region of Western Port receives the majority of freshwater input from the catchment and is also the most poorly flushed area. As a result, sediments and associated pollutants delivered in river discharge remain in the system for a considerable time. The majority of the catchment is used for agriculture, including highly productive horticultural areas such as the Koo-Wee-Rup district, a low-lying swampy area that has been extensively channelled to provide drainage and flood mitigation. Much of Western Port is very shallow, with about 40 percent exposed as mudflats at low tide.

The bay is biologically more diverse than its larger neighbour, Port Phillip Bay, due to the wide range of key habitats present, including reefs and macroalgae in deeper waters, and large areas of seagrass (90 km²), mangrove (37 km²), saltmarsh (310 km²) and other wetland habitats. These form a wetland system of international importance (Ramsar listed), providing habitat for the 15,000 migratory water birds that visit Western Port each year. The wetlands help to prevent erosion by stabilising coastal areas and help to filter and recycle sediments and nutrients from the catchment and within the bay.

Western Port's seagrass beds are feeding and nursery areas for a range of commercial and recreational fish species and support a diverse invertebrate community. Sedimentation and ongoing turbidity/resuspension of sediments along with run-off containing herbicides and pesticides from agricultural land are associated with a loss of 70 percent of seagrass cover since the 1970s. The exact causes of the decline are unknown. There has been some revival of the Western Port seagrass beds in recent years, however the reasons for this are unclear. Research into potential restoration of seagrass areas is currently helping promote the natural regrowth of seagrass in Western Port. Mangroves were historically removed from the bay to provide better access for sea transport to Melbourne and to reclaim land for farming. Sedimentation led to further losses, but some mangrove areas have since regenerated.

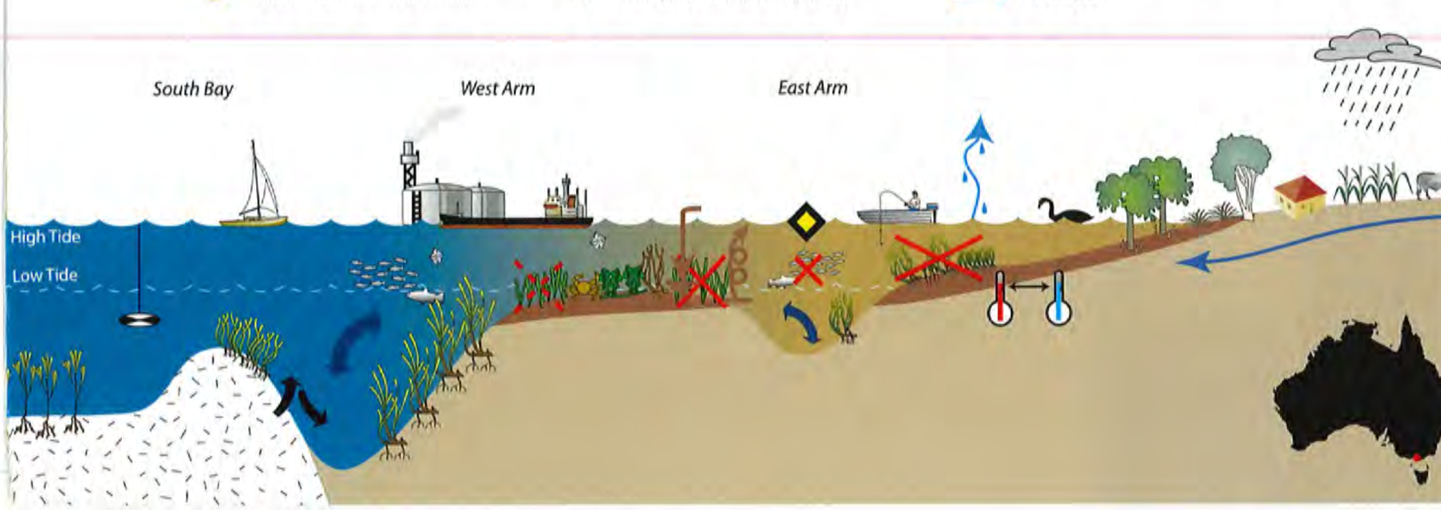


Western Port Yacht Club (above); Hapophila seagrass at Coronet Bay, Western Port (right); Mangroves (Avicennia marina) at Western Port (facing)

Key issue: seagrass loss

- Agricultural land use also includes orchards, market gardens, viticulture and poultry
- The majority of stream flow from the catchment is discharged into the east arm
- Sediment types: coarse sand/shell, fine-grained mud, organic-rich sediment
- Water clarity is high in the entrances and north arm and low in the east arm
- The south bay is well flushed by oceanic waters
- Seagrass: *Amphibolis, Zostera, Heterozostera, Halophila ovalis* ... approx. 90 km² of seagrass
- Smothering and burial of seagrass
- Decline of seagrass contributes to sediment resuspension
- Large areas of seagrass in the eastern bay are increasingly exposed to desiccation
- Extremes of temperature are experienced in the shallow eastern bay
- 70% of seagrass was lost from Western Port from 1970s to 1983
- Gradual improvement has occurred in seagrass beds with up to 20% recovery in isolated areas
- Macroalgae (*Caulerpa*) has recolonised areas of seagrass loss in lower east arm
- Flushing of channels in the east arm reduces sediment buildup
- Seagrass has survived in deeper channels due to reduced exposure and smothering

- Average rainfall in the catchment varies from 750 mm to 1200 mm
- Catchment agriculture is dominated by cattle and sheep grazing, and dairies
- Major industry includes an oil refinery, a gas fractionalisation plant and steel works
- Ports/shipping
- About 150,000 people live in a number of small to medium-sized towns in the catchment
- Boating
- Recreational fishing
- Commercial fisheries have declined by 46% between 1978 and 1997
- 4 of 16 introduced species are targeted as marine pests e.g. the European shore crab
- The introduced dinoflagellates *Alexandrium* and *Gymnodinium* are found in the bay
- Western Port is fringed by about 37 km² of mangrove forests
- Coastal vegetation is dominated by saltmarsh communities (310 km²)
- *Melaleuca* wetlands
- Seagrass beds and other wetlands are habitat and nursery areas for many fish species
- Some 15,000 migratory water birds visit Western Port each year

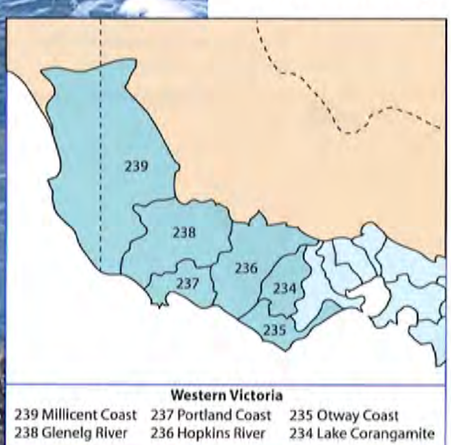


Western Victoria

Small inlets, big waves

Western Victoria, from Thompson Creek near the entrance to Port Phillip Bay west to the Glenelg River near the South Australian border, has a temperate Mediterranean climate with a winter/spring wet season and a summer/autumn dry. Rivers are thus strongly seasonal and during winter and spring energetic flows may maintain open estuary mouths. The coast is micro-tidal with mean spring tides of less than 1.5 m.

The estuaries of Western Victoria, from Thompson Creek outside Port Phillip Bay to the Glenelg River on the South Australian border, are mostly small and wave-dominated. Catchments are short, mostly steep and the coastline is exposed to high wave energy from the Southern Ocean. The eastern part of the region is the Otway coast, a narrow coastal plain facing southeast at the base of the Otway Ranges. This area is among the wettest in Victoria, with rainfall varying from about 600 mm in the north to around 1200 mm in the south, and higher in the ranges, which support pockets of temperate rainforest.



West from Cape Otway, the coast faces the prevailing swell direction and so bears the full brunt of ocean waves. Portland Bay is the only deepwater port between Geelong and Adelaide. Active erosion of the coastline has led to the formation of spectacular cliffs such as those along the Port Campbell coast. This area is drier, with rainfall from 600 to 800 mm. It is characterised by flat limestone plains and geologically recent volcanic activity. Inland lie the western plains, one of Australia's richest wool-producing areas, but an area also highly susceptible to erosion. In general, the small coastal lagoons of western Victoria support a less diverse flora and fauna than the larger estuaries and bays to the east. Seagrass cover is sparse and mangroves are naturally absent from these estuaries.

Spectacular limestone – Port Campbell coast

Driving the Great Ocean Road

The Great Ocean Road is a spectacular drive winding for about 280 km between Geelong and Warrnambool. Between rugged rocky outcrops and headlands lie many beaches, including world-class surfing beaches such as Bells Beach near Torquay. Travelling southwest between

Anglesea and Apollo Bay, the road hugs the coast with the steep forested slopes of the Otway Ranges on one side and the ocean on the other. At Apollo Bay, the road leaves the coast and winds through the temperate rainforests and tall eucalypt forests of Cape Otway. Many waterfalls and bush tracks are accessible in the ranges. One of several lighthouses on the coastline is situated at Cape Otway. Past the cape, the coast runs in a more northwesterly direction. In days of sail, Melbourne-bound ships screamed out of the Southern Ocean's vast expanse to 'thread the needle' between Cape Otway and King Island. More than 80 were lost to wild seas in the area, now known as 'the shipwreck coast'. Here the road follows the coast through Port Campbell National Park, famous for spectacular limestone cliffs and other rock formations including the 12 Apostles, the Grotto, London Bridge and Loch Ard Gorge. At the western end of the road at Warrnambool, calving southern right whales can be seen between June and October.

Opening the mouth

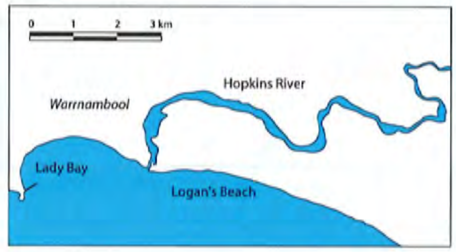
The catchments of this region are in a vast hinterland producing mainly wool and grain, though significant wilderness areas with high recreational value exist (e.g. the Otways). Several estuaries function as minor ports. The region has the greatest number of modified estuaries, many at risk from inappropriate land uses and extractive uses.

The artificial opening of estuary mouths is an important issue in the west of Victoria. Many of these estuaries have only ephemeral openings to the coast. The catchment is often steep and predominantly agricultural. Nutrients, sediment and toxic substances can accumulate in the estuaries. Local groups with permits sometimes open entrances artificially to prevent flooding of farms and residences, improve water quality and to promote fish recruitment. The artificial opening, however, can cause environmental problems such as reduced water quality and fish kills. Wetlands also rely on periods of flooding and opening the estuaries can prevent this. Several estuaries are popular for recreational fishing with mulloway and southern black bream, for example, being popular recreational fish caught in the Glenelg River estuary. One estuary in the west, Gellibrand River, has the only complete estuary management plan in Victoria, including protocols for estuary mouth opening.

Interpretive signage tells the story of the Loch Ard *shipwreck (above); Port Fairy lighthouse (below)*

Lake Yambuk, west of Port Fairy, is periodically closed to the sea

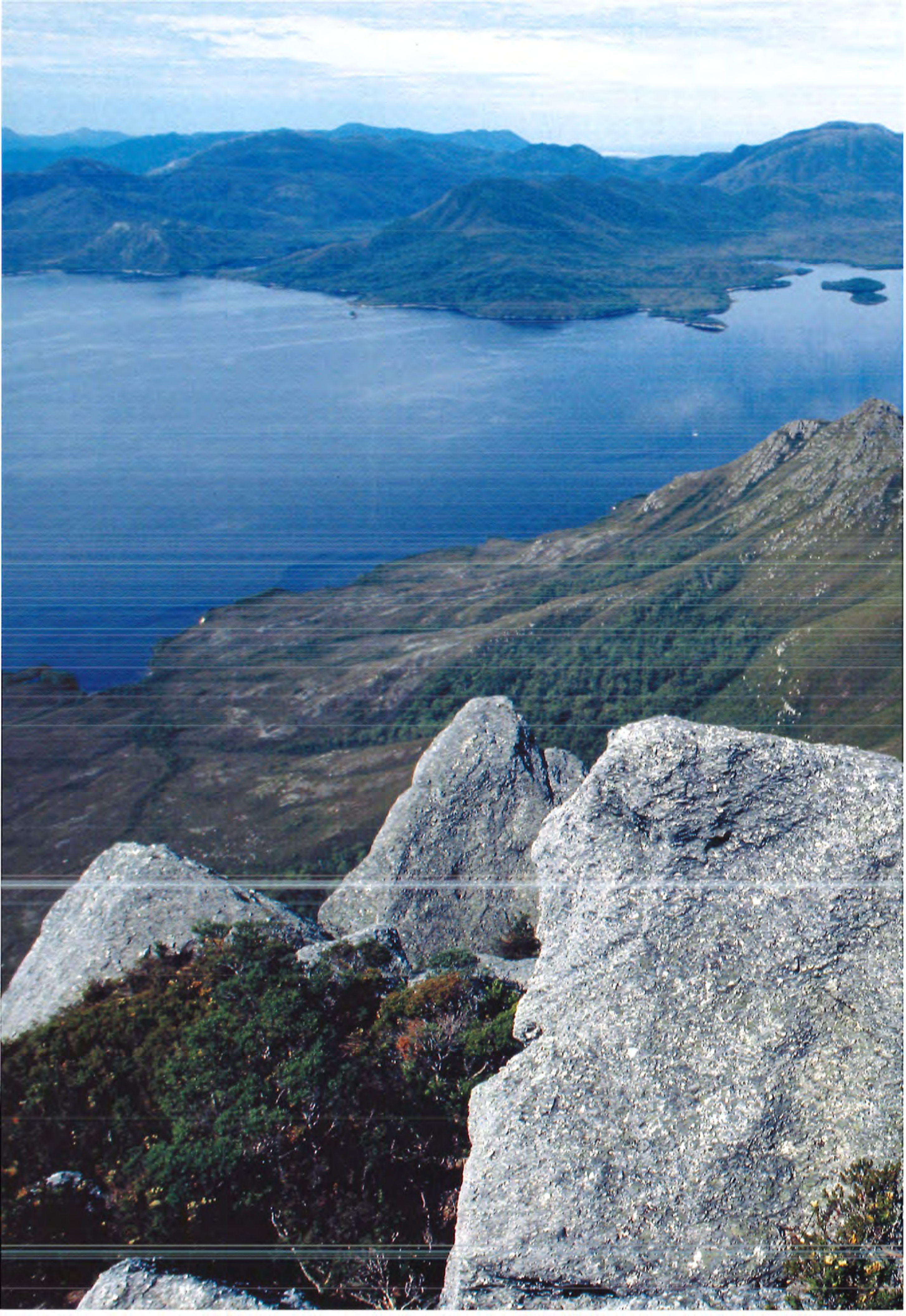
Case study: Hopkins River



The Hopkins River estuary, site of the city of Warrnambool (population 26,000) is located on the Great Ocean Road roughly midway along the 'shipwreck coast'. Like other estuaries in the region, the Hopkins has a seasonally open sand bar at the mouth. During winter and spring, consistent freshwater flows keep the mouth of the estuary open. As discharge drops in summer, sand transported by longshore drift is carried into the estuary to re-establish the flood-tide delta and eventually the sand bar which may close the mouth completely. Once the mouth is closed in this way, the water level slowly rises due to a net gain of water through river discharge and seawater incursion over the bar during high seas. Strong winds can efficiently mix and re-oxygenate surface waters to depths of several metres. Deeper, more saline waters lack oxygen due to the formation of layers which inhibit mixing. Lack of tidal and river flows also reduces mixing. As a result, the Hopkins estuary, which can be completely fresh during floods, becomes highly stratified during low flow conditions. It is likely though that the frequency and duration of mouth closure has increased as a result of increased water diversion for stock and domestic use, irrigation and urban water supply.

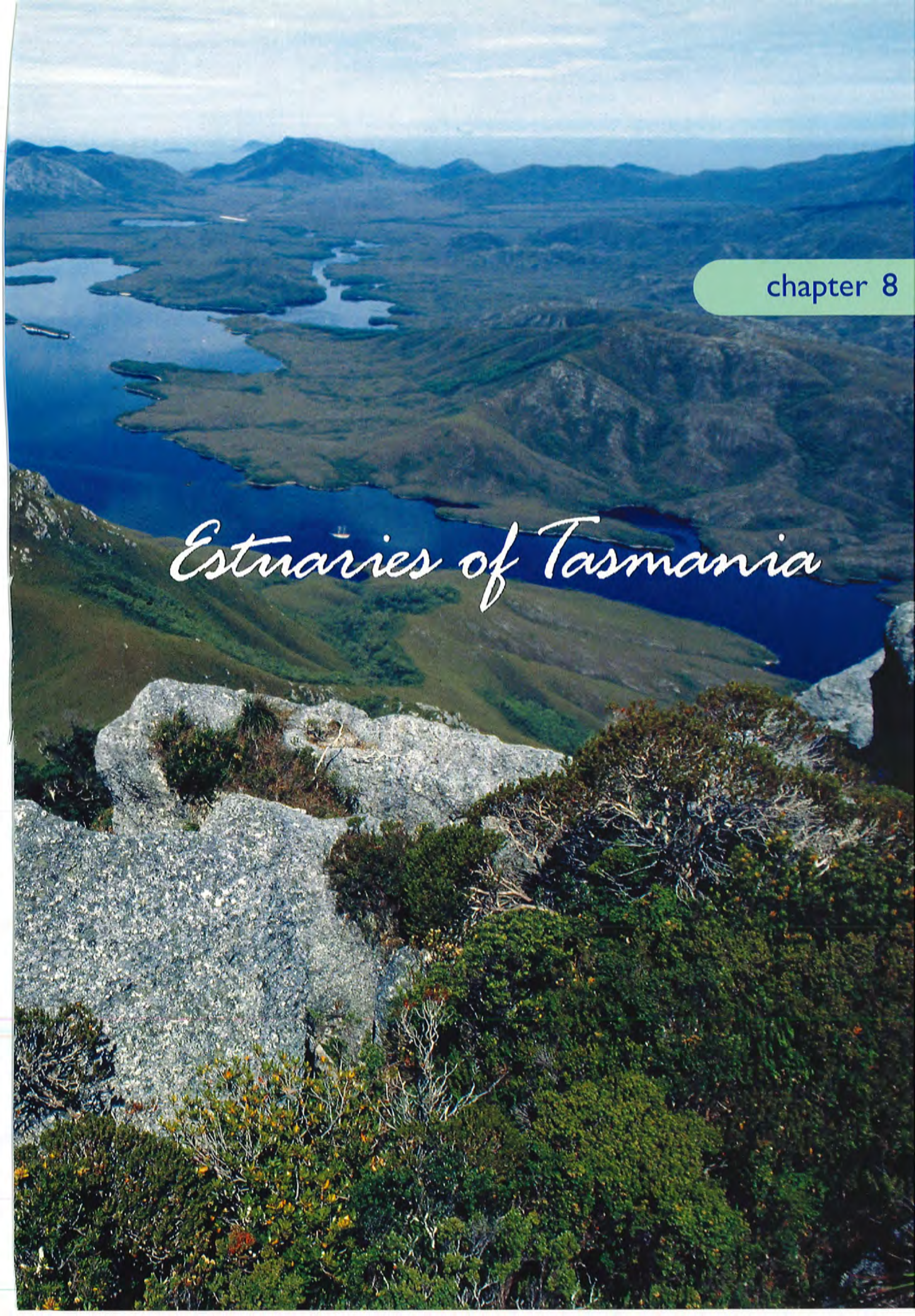
Mouth closure has had a range of impacts including inundation of built structures such as boat houses and jetties, drowning of floodplain areas used for summer grazing and loss of amenity as boat ramps and jetties became unusable. Prior to southwest Victoria's first documented fish kill associated with mouth opening (on the Surry River in 1999), mouth opening had been undertaken by the local community as required. This was done with few protocols and without assessment of environmental effects. Protocols have since been developed to ensure environmental effects are considered in planning the timing of openings. A major concern for the Hopkins estuary is that opening may remove the surface oxygenated water layer leaving only the deeper anoxic water. At times, oxygenated water has been restricted to a layer within 1m of the surface. If opened at these times fish kills could result. Monitoring of openings has increased understanding of important factors causing undesirable environmental effects.

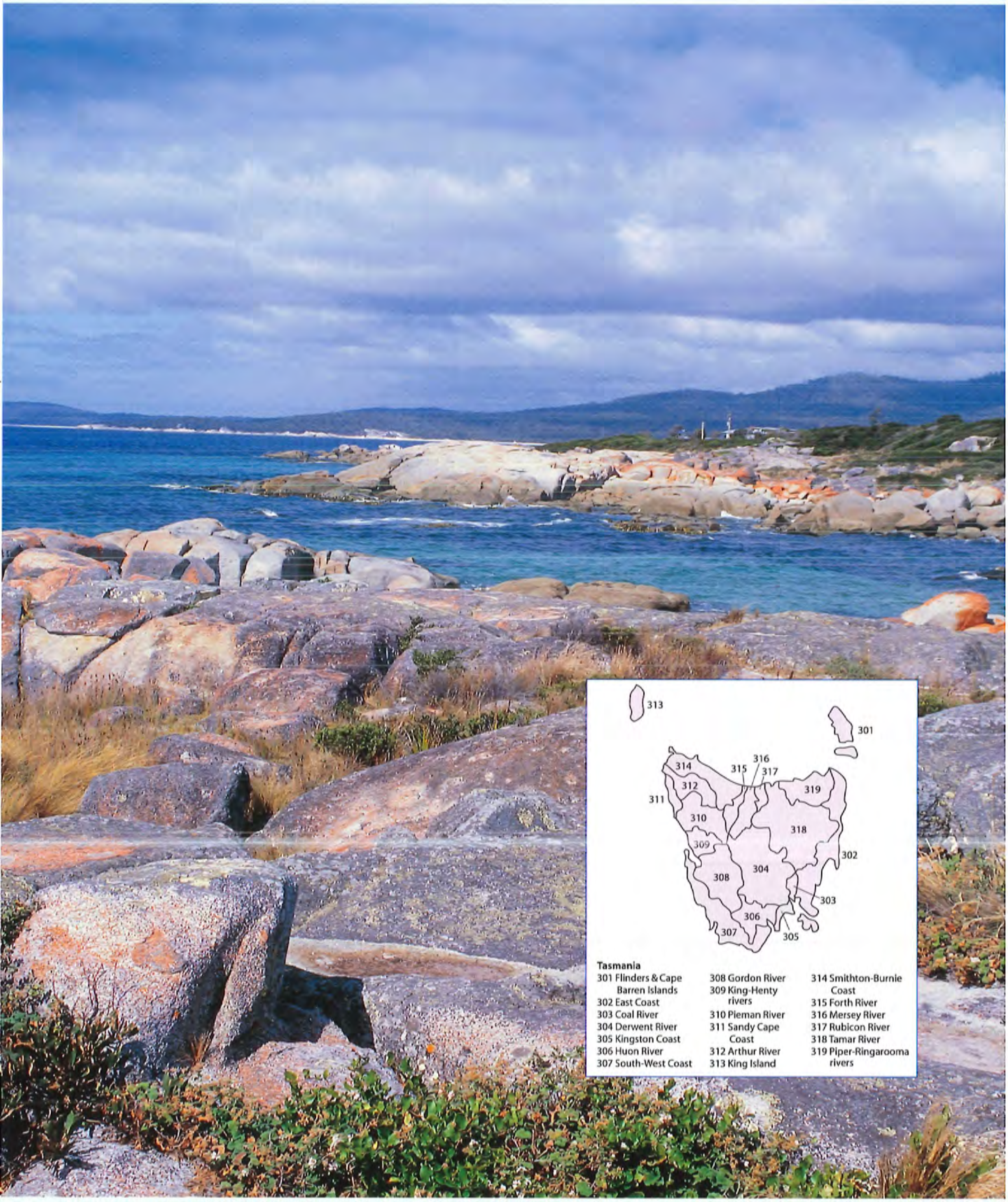
Estuary management in Victoria	
Management arrangements	In Victoria, responsibility for estuaries spreads across several agencies with no formal coordination. A number of Coastal Action Plans and specific State Environment Protection Policies have been developed. There are several current and proposed marine protected areas and designated aquaculture areas.
Key issues	• population growth and expanding coastal development • many of Victoria's western estuaries are at risk from inappropriate land use, high erosion rates within the catchment and accumulation of toxicants, nutrients and sediments due to their ephemeral nature • use of flood mitigation processes which can cause environmental problems • reduced flows of several estuaries due to water extraction upstream • modification of many of central Victoria's rivers and catchments has resulted in increased inputs of sediments, toxicants and nutrients into the waterways • control of exotic aquatic flora and fauna • greater public access to estuary information and education
Key management responsibility	The principle agencies include: • **Environment Protection Authority (EPA)** – controlling the discharge of wastes to the environment and preventing pollution, assessing water quality • **Department of Sustainability & Environment (DSE); Department of Primary Industries (DPI)** – overseeing the management of the land and resources of Victoria's coastal public land and marine resources for conservation and recreational uses • **Parks Victoria** – manage Victoria's national, state, marine, regional and metropolitan parks and conservation reserves • **Victorian Coastal Council and Regional Coastal Boards** – implement strategic planning for Victoria's coastal resources, including estuaries • **Victorian Catchment Management Council (VCMC)** – three Regional Coastal Boards (Gippsland, Central and Western) are responsible for developing and implementing regional Coastal Action Plans • **Catchment Management Authorities (CMAs)** and **Catchment Land Protection Boards (CaLP)** – ensure sustainable development of natural resources and maintain and improve land and water resources in their region through Catchment Strategies
Policy and legislation	• ***Environment Protection Act 1970*** provides an over-arching legislative framework for environment protection in Victoria. • **State Environment Protection Policies (Waters of Victoria)** sets out a framework for protection of fresh, marine and estuarine environments. • Schedules (F4, F6, F7 and F8) to Waters of Victoria for Gippsland Lakes, Port Phillip Bay, the Yarra River and Western Port set region specific attainment programs. • ***Coastal Management Act 1995*** • **Victorian Coastal Strategy** protects significant features, gives direction for coast use, identifies development areas and ensures sustainable resource use. • **Coastal Action Plans** identify strategic directions and objectives for use and development in the region. • **Environment Management Plans** – Port Phillip Bay SEPP has drafted an EMP. EMPs for Port of Melbourne, Hastings and Portland are being prepared. • **Ramsar** sites; Parks Victoria's **Strategic Management Plan** for listed waters • ***Crown Land (Reserves) Act 1978***; **Municipal Planning Schemes; Regional Catchment Strategies; Neighbourhood Environment Improvement Plans; Fisheries and Park plans and strategies; Melbourne's Metro Strategy; Biosphere** and **Watermark Program**
Community initiatives	• **Coastcare, Land for Wildlife, Fishcare** and **Landcare** • **Marine and Coastal Community Network** • **Habitat assessment groups; Waterwatch Victoria; Western Port Seagrass Partnership**



chapter 8

Estuaries of Tasmania

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Tasmania
301 Flinders & Cape Barren Islands
302 East Coast
303 Coal River
304 Derwent River
305 Kingston Coast
306 Huon River
307 South-West Coast
308 Gordon River
309 King-Henty rivers
310 Pieman River
311 Sandy Cape Coast
312 Arthur River
313 King Island
314 Smithton-Burnie Coast
315 Forth River
316 Mersey River
317 Rubicon River
318 Tamar River
319 Piper-Ringarooma rivers

Some of the most pristine estuaries in Australia are found in southern Tasmania. Bathurst Harbour and New River Lagoon, within the southwest World Heritage Area are two of these. Tasmanian estuaries are diverse. Differences in wave energy and rainfall between west and east, a bigger tide range in the north and topography contribute to diversity. Hobart and Launceston are on the shores of the Derwent and Tamar estuaries, respectively. Both are severely modified yet still have high levels of biodiversity with much wildlife found nowhere else in the world. As Tasmania is an island, many larger estuaries are important for shipping. Estuaries, such as the Huon estuary and d'Entrecasteaux Channel are important for marine farming and recreation.

Of Tasmania's non-pristine estuaries, many are degraded by agriculture, forestry and urban development. Sewage, run-off and industrial pollution reduce water quality in urban estuaries. Agriculture and land clearing have brought nutrients and sediment to estuaries, particularly in the northeast and northwest. Some estuaries have suffered mining impacts, such as Macquarie Harbour (heavy metals) and Boobyalla and Ringarooma estuaries (siltation). In estuaries with upstream hydroelectric dams or irrigation, environmental flow is an issue.

Introduced marine pests are a concern in many Tasmanian estuaries. Such pests can threaten the ecology of estuaries by altering habitat or outcompeting/preying on local species. Introduced pests include toxic dinoflagellates, Northern Pacific seastars (*Asterias amurensis*) and New Zealand screwshells (*Maoricolpus roseus*) in the d'Entrecasteaux Channel, Derwent and Huon rivers. Introduced rice grass occurs in many estuaries, particularly Tamar River and Port Sorell.

Resource allocation is a major issue in some Tasmanian estuaries. Commercial and recreational fisheries, marine farms and other coastal developments all compete for resources. Some estuaries provide a cultural and historical centre for coastal communities. Balancing these uses with conservation is a significant issue for estuary managers.

Regions

- ## *Northern Tasmania*

  (from Welcome Inlet to Great Musselroe)

- ## *Eastern Tasmania*

  (from Anson's Bay to Blackman Bay)

- ## *Southeast Tasmania*

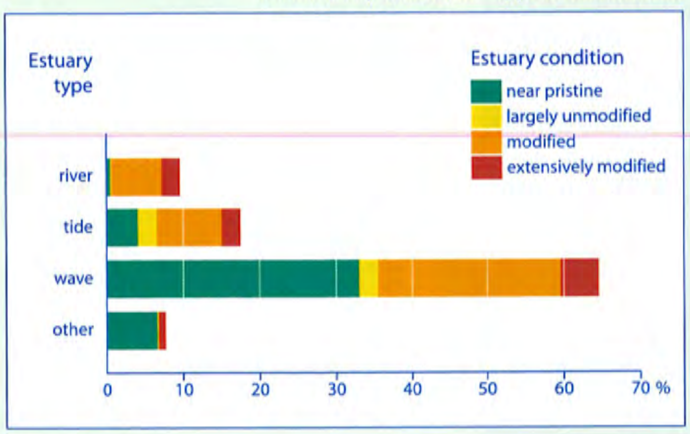
  (from Carlton to Southport Lagoon)

- ## *South and West Tasmania*

  (from d'Entrecasteaux to Arthur)

- ## *Bass Strait Islands*

Estuaries of Tasmania – type and condition



Northern Tasmania

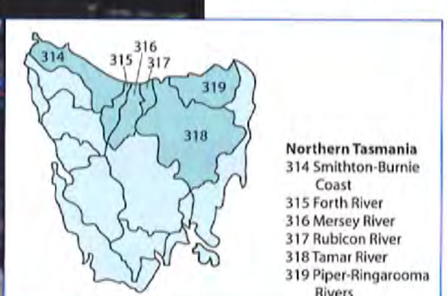
Rivers into Bass Strait

Estuaries along the Bass Strait coastline, from Cape Grim to Cape Portland are influenced by a mild climate. The catchments receive moderate but seasonal rainfall and have relatively high tidal ranges of up to 3 m. Despite this, the region includes a range of both wave- and tide-dominated systems. Seawater temperatures are higher than in the south of the state due to the influence of warmer waters from the Great Australian Bight which extend to the northwest coast during the cooler months. The East Australian Current to Tasmania's northeast coast also raises the sea temperature, particularly in late summer. Rivers in the northwest have higher, more predictable flows than rivers in the central north and northeast. Stratification commonly occurs in northern Tasmanian estuaries during periods of average river flow.

The Tamar estuary has extremely high plant, invertebrate and fish diversity.

Old factories

Some of Tasmania's major industries have developed in the north beside the port facilities offered by river estuaries such as the Tamar, Mersey and Don River estuaries. In the 1850s the Don River township, a few kilometres west of the current city of Devonport, was an industrial centre built around saw-milling and shipbuilding. In Devonport, carpet manufacturing factories were established in the 1960s and continue production today.



The Esk Brewery was established in 1881 on the banks of the Tamar River and continues to produce world class beers and ales. The Waverley woollen mill began production in 1874 and remains one of Australia's largest producers of woollen textiles. In the 1950s, the industrial port at Bell Bay near George Town was the first site in Australia to produce aluminium and the site is still one of the largest aluminium smelting works in the Southern Hemisphere. Woodchip and paper mills, a thermal power station and large oil installations maintain an industrial focus on the lower Tamar estuary. Part of the industrial history of Launceston can be seen at the Inveresk railyards on the upper Tamar estuary. First built in the 1870s as an industrious railyard, the site has now been converted to a museum.

Business as usual?

Nearly all estuaries on the northern coast of Tasmania have been significantly modified by human activities. Impacts include the direct results of adjacent development and indirect effects including contamination, siltation and nutrient enrichment. Many catchments are extensively cleared for agriculture (particularly vegetable crops) supported by the relatively high rainfall, mild climate and rich soils. This has contributed to problems of high sediment loads in flood run-off. Mudflat areas in estuaries expand, often replacing sandy beds and shores. This in turn leads to changes in the animal and plant communities supported by the estuary. High sediment loads are responsible for a variety of ecological and economic impacts. These include smothering bottom-dwelling plants and animals, reducing light penetration to aquatic plants and creating the need for regular navigational dredging to maintain shipping channels. For example, approximately 50,000 to 80,000 m^3 of silt has to be removed by the Port of Devonport every three years at a cost of up to $7 per cubic metre. Regular settling and re-suspension of sediment particles due to tidal mixing threatens seagrass beds and other ecological communities on the seafloor. The presence of contaminants in sediment from urban, industrial and agricultural sources and from the physical disturbance of benthic habitats due to dredging also threatens seafloor communities. As well, sedimentation impacts on recreational users of estuaries in the region, such as water-skiers and rowers, due to the expansion of mudflats and accumulation of hazards such as logs and driftwood.

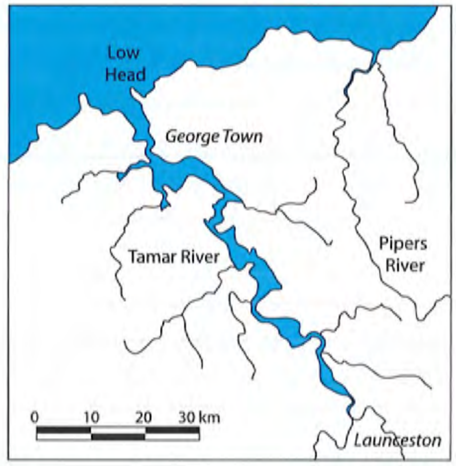
The location of a variety of industries adjacent to estuaries, including sawmilling and a pulp and paper mill, has brought a range of impacts. These include metal contamination of sediments and a reduction in the levels of dissolved oxygen in the water due to bacterial decay of discharged organic matter. Urban areas, including Devonport and Launceston and some smaller regional centres, have high levels of sediments, nutrients and various toxic substances being discharged to estuaries through sewerage and stormwater drains. A number of pest species, introduced both deliberately (e.g. rice grass, *Spartina anglica* in the Tamar) and accidentally (e.g. the European crab, *Carcinus maenas* and the fan worm, *Sabella spallanzani*, in the Mersey) threaten estuarine ecosystems in northern Tasmania.

From top: Mersey River industrial site; rice grass is a pest on the Tamar Estuary; Port Sorrel, the oldest town on the northwest coast of Tasmania

Case study: Tamar River

Port Dalrymple and the River Tamar occupy the bottom of a valley betwixt two irregular chains of hills, which shoot off northwestward, from the great body of inland mountains. In some places, these hills stand wide apart, and the river then opens its banks to a considerable extent; in others, they nearly meet, and contract its bed to narrow limits.

Matthew Flinders



The Tamar River estuary is a drowned river valley that appeared to Matthew Flinders to have "more the appearance of a chain of lakes, than of a regularly formed river". It is the site of the city of Launceston with a population of about 66,000 making it Tasmania's second largest city. Launceston is located at the top of the estuary near the confluence of the North and South Esk rivers, the latter being the longest river in Tasmania. The estuary has been extensively changed by human activities over the past 130 years, but in areas it remains an exceptionally diverse ecosystem.

Mining in the catchment began in the 1870s and smelters continued to discharge into the river until the early 20th century. Acid- and metal-contaminated water continues to enter the river from several former mining areas. A range of other industries developed

near Launceston and along the lower estuary and for many years they discharged into the river but generated little environmental concern. The estuary is still affected by a number of industries including an aluminium plant and woodchip mill. For many years, Launceston also discharged raw sewage directly to the Tamar. The legacy of these practices is sediment contamination by a range of metals. As a result, filter-feeding organisms such as oysters have become unsafe to eat throughout much of the estuary.

The Tamar catchment has been extensively cleared for agriculture including dairying, sheep and cattle grazing, and a range of crops. This has destabilised soils in the catchment and extremely high loads of silt are periodically deposited in the estuary, requiring dredging to maintain shipping channels and causing expansion of mudflats along the shoreline.

The estuary is also affected by a number of introduced species including rice grass, *Spartina anglica*, which was introduced in 1947 to stabilise intertidal mudflats and constrain channel movements but has spread uncontrolled. Despite these problems, the estuary still supports a rich biological community, including many species not found in other Tasmanian estuaries. Invertebrate and fish diversity in seagrass beds at the mouth of the Tamar may be the highest of any estuary in mainland Tasmania and the estuary provides an important refuge for waterbirds.

The Tamar is also a major recreational resource for the people of Launceston as a site for fishing, swimming, boating and sailing. There is growing recognition that past (and present) practices have severely degraded the Tamar and groups such as 'Friends of the Tamar' are committed to restoring the health of the estuary ecosystem and protecting natural areas that remain intact.

Tamar River (top and facing); Launceston Gorge (right)

Eastern Tasmania

Dry catchments, small lagoons

Eastern catchments have the lowest rainfall on the Tasmanian coast. So the estuaries from Cape Portland to Maria Island are influenced by fairly low unpredictable flows. The region has many small coastal lagoons, particularly along the northeast. These lagoons and other estuaries tend to be well mixed compared to other Tasmanian estuaries.

Big old farms

Eastern Tasmania has a long history of farming enterprise and resourcefulness with Great Swanport being the first rural municipality in the state. Early farms were isolated, being midway between Launceston and Hobart. Farm industries included orcharding, hop growing, wool and grain production, beef cattle and sheep. Wheat was an important crop, supplying the early community with its staple food. Whaling was also carried out here.

Eastern Tasmania
302 East Coast

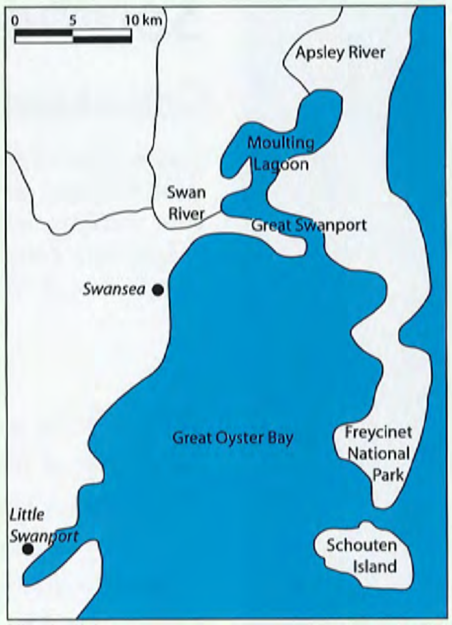
More recently this area has become renowned as the location of a number of stunning coastal national parks, including Freycinet and Maria Island. The Freycinet Peninsula is rugged and beautiful with outcrops of pink granite, white sand beaches and azure bays. Bushwalking, scenic drives and wildlife spotting are popular activities.

Erosion into lagoons

Land use includes agriculture and forestry. The impact of these industries on estuarine water quality and ecosystems is more marked because the modified estuaries are mostly wave-dominated. A recent report on the distribution of inshore marine organisms concluded that virtually all estuaries on the east and north coasts of mainland Tasmania are degraded by pollution, siltation, nutrients and onshore development.

Case study: Great Swanport

The near-pristine Great Swanport estuary is a large wave-dominated estuary with freshwater input coming from two major rivers; the Swan and Apsley. The nearby historic town of Swansea was originally know as Great Swanport and is a popular tourist site for visitors to the east coast and Freycinet National Park. A temperate maritime climate combined with low rainfall provides some of the warmest and best weather in the state.



Great Swanport and Moulting Lagoon comprise the Moulting Lagoon Game Reserve which is a wetland of international importance under the Ramsar convention. Large expanses of sandflats and mudflats are exposed at low tide providing habitat for a large number of waterbirds and the estuary contains the largest concentration of black swans in Tasmania. Hunting for ducks occurs during an open season and the area has historically been used by Aboriginal people to harvest waterbirds. Recreational fishing and boating are popular within the estuary and several oyster farms exist within the middle reaches of Great Swanport.

Much of the surrounding foreshore is contained within grazing properties. However, fencing has been used to exclude stock from some sensitive samphire vegetation.

Great Swanport (below); Moulting Lagoon and Hazards (facing, top); historical Swansea (facing, bottom)

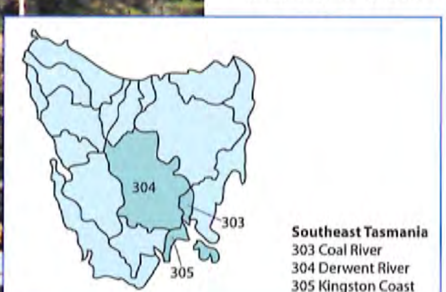
Southeast Tasmania

Convoluted coastline

It seems that all the safe shelters of New Holland are assembled in the regions close to South Cape, east of which are to be found an uninterrupted succession of havens, ports and bays, which form vast shelters of eighteen leagues in latitude and fourteen in longitude. I do not believe that such a large number of excellent anchorages exists in such a small space, anywhere in the world.

Bruny d'Entrecasteaux, *Voyage to Australia and the Pacific*

One of the most characteristic features of the southeast coast of Tasmania is the highly convoluted coastline, with many protected embayments from Maria Island to Southport. The circumpolar Antarctic current that brings cold nutrient-rich waters to the southern coast of Tasmania influences larger estuaries in this region. Low to moderate rainfall is spread throughout the year, though summers can be very dry. Parts of the Derwent River valley are the driest in Tasmania, with falls as low as 500 mm per year. Coastal areas in the far southeast are exposed to southwesterly winds so rainfall is higher in these areas. In lowland and coastal areas of the southeast, rivers have low run-off and the greatest variability of flow in the state. Many of the estuaries stratify in winter when river flows are high and are partially mixed in summer. Both wave- and tide-dominated systems are present.



The estuaries have many endemic plants and animals, including the spotted handfish *(Brachionichthys hirsutus)* which is listed as a threatened species.

Farming the sea

The suitability of Tasmanian waters for caged Atlantic salmon (*Salmo salar*) farming was noted by a Norwegian salmon expert in the early 1980s. From an initial harvest of 53 tonnes in 1986–87, marine salmon (and rainbow trout) farming expanded rapidly through the 1990s to become one of Tasmania's major industries. Production grew to 16,000 tonnes by 2001 although compared to other major salmon farming countries such as Norway (250,000 tonnes) and Chile (110,000 tonnes) production is small scale. Other species farmed commercially in Tasmania include oysters, mussels, abalone, scallops, seahorses and rock lobsters. Marine farming operations are licensed under the *Living Marine Resources Management Act 1995*, which requires strict management controls to ensure environmental standards are met.

Industrial wastes and uninvited guests

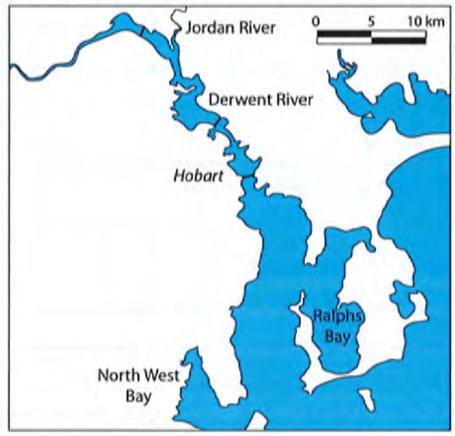
Land use includes agriculture, forestry and urban and industrial developments. Most estuaries in this part of Tasmania are considered to be modified. Tasmania has been particularly hard hit by introduced species. The northern Pacific seastar is a voracious predator of native shellfish and affects oyster production on some shellfish farms. Another introduced species is the toxic dinoflagellate *Gymnodinium catenatum* that has caused the closure of some oyster leases in the Huon estuary as well as causing minor blooms in the Derwent in recent years. Finfish farming is a rapidly growing enterprise in Tasmanian marine waters although it is associated with increased organic loading through waste products and uneaten food that can accumulate below cages. At present, the impact of this organic pollution is considered to be localised and affected sediments are thought to recover once cages are removed.

Estuaries in southeast Tasmania support oyster production (facing and below); the dramatic convoluted coastline of the Tasman Peninsula (bottom)

Case study: Derwent River

M. Willaumez reached the entrance of a large inlet, which he took at first for a strait… At approximately four leagues inside the entrance, the boat stopped near an elbow, beyond which it was easy to recognize that what had been taken for a strait, was in fact the estuary of a quite mighty river…, which we have named Rivière du Nord [later renamed the Derwent River].

Bruny d'Entrecasteaux, *Voyage to Australia and the Pacific*



The Derwent estuary, flanked by the city of Hobart, is a diverse ecosystem and a valuable scenic, recreational and economic resource. It is a large drowned river valley that widens and deepens considerably in the lower reaches. The area has a cool, temperate climate. Average rainfall is about 600 mm. Forty percent of Tasmania's population lives adjacent to the estuary, which is used for recreation, boating, fishing, transport and industry. Upstream, the Derwent has been dammed for hydroelectricity generation and to supply drinking water to most of the region's population.

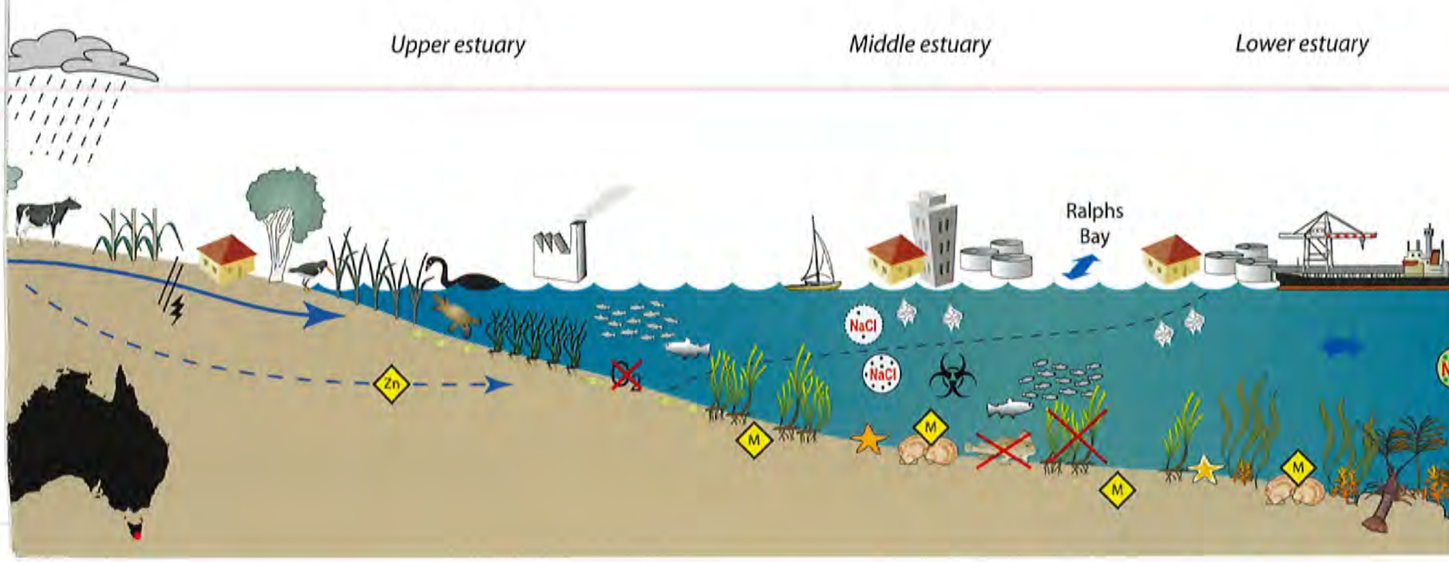
The catchment is used for agriculture, including cultivation of hops. In the past, the estuary was used as a dumping ground for industry so it is very degraded in many areas. A number of industries still discharge into the river. In the past, industrial wastes were discharged to the Derwent with minimal treatment, resulting in severe heavy metal contamination of sediments and shellfish.

Hobart, Derwent Estuary, Mount Wellington (Wrest Point Casino in the foreground)

- Mean average annual rainfall is around 570 mm per year
- 52% of the catchment remains as woodland, forest and rainforest
- Sheep and cattle grazing is the main agricultural activity in the catchment
- Smaller areas are cultivated for crops such as vegetables, hops, poppies and oil crops
- Residential areas contribute nutrient, sediment and faecal bacteria loads to the estuary
- Dams for hydroelectricity have reduced flows from catchment rivers and streams
- Groundwater contamination from zinc processing activities has been an issue
- The city of Hobart spans the middle reaches of the Derwent estuary
- 10 sewage treatement plants discharge into the estuary
- Salinity stratification results from high freshwater flows
- Elevated levels of faecal bacteria indicate that certain areas pose health risks from human pathogens
- Wetlands provide important habitat and nursery areas and act as natural filter systems
- Waterbirds frequent wetlands and tidal flats in the upper estuary and Ralphs Bay
- Platypus occur in wetland areas in the upper reaches of the estuary
- Seagrass: *Ruppia* are dominant in the upper reaches
- Small patches of seagrass *Zostera* and *Heterozostera* occur in the middle and lower estuary
- Heavy metals are present in the sediments
- Heavy metals are present in shellfish and other bottom-dwelling organisms
- Industry including ANM paper plant and Pasminco Hobart smelter
- Oxygen depletion of bottom waters occurs in the upper estuary (caused by both natural settling/processes plus inputs from pulp mill)
- Recreational species include bream, brown trout, short-finned eel, whitebait and flathead
- Endangered species: the spotted handfish has undergone dramatic decline
- Kelp and other macroalgae form unique communities in the lower estuary
- Rocky reef habitats in the lower estuary support species such as rock lobster
- Benthic microalgae and other microorganisms are present in the sediments
- Invasive species including the northern Pacific seastar are of major concern
- Blooms of the toxic dinoflagellate, *Gymnodinium catenatum* have occurred in recent years
- Extensive areas of seagrass have been lost from the middle estuary (Ralphs Bay)
- The Derwent is very popular for boating and other recreational activities
- Impacts of shipping include ballast water discharge
- Tidal exchange with the ocean
- Exchange with Ralphs Bay
- Oceanic waters are naturally high in nutrients

Introduced marine pests are a major problem, particularly the northern Pacific seastar, which has colonised large areas of the estuary and continues to threaten a number of native organisms. Other environmental issues facing the Derwent include nutrients from sewage and urban run-off, loss of habitat and species, faecal contamination of recreational waters, oxygen depletion of bottom waters and alteration to natural flow regimes. Increasingly, people are realising that the Derwent's ecosystem has been badly degraded by human activities but it is not beyond recovery. Growing community concern and active interest in the Derwent's health have led to efforts to clean up the estuary. The Derwent Estuary Program was initiated in 1999 as a joint state, local and commonwealth government initiative to restore and protect the waterway and to enable management efforts to be coordinated.

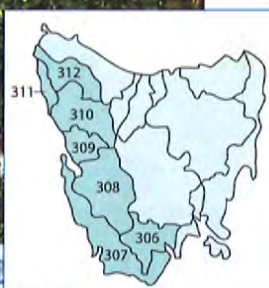
The Derwent River in autumn



South and West Tasmania

Wet, wild and windy with tea-coloured waters

The south and west coast, from Southport to Cape Grim, has high rainfall, with much of the coastline exposed to extremely high wave energy. Both of these features are largely the result of the 'roaring forties', the westerly trade winds. These influences bring rain for most of the year except when they are pushed south by the belt of high pressure systems that moves across southern Australia during late summer. Estuaries in this region are also influenced by the cold Antarctic circumpolar current. After the wet tropics of northern Queensland, the southwest of Tasmania is the wettest part of Australia. As a result, river flows are relatively high and consistent. Rainfall in the southwest highlands exceeds 3000 mm per year in some places, though coastal areas receive closer to 1500 mm per year and rainfall decreases to the northwest.



South and West Tasmania
306 Huon River
307 South-West Coast
308 Gordon River
309 King-Henty rivers
310 Pieman River
311 Sandy Cape Coast
312 Arthur River

Much of southwest Tasmania is rugged, remote terrain forming the Tasmanian Wilderness World Heritage Area, so most of the estuaries in this region remain in near-pristine condition. One of the key features of these estuaries is the influence of dark, tannin-stained water that leaches from extensive areas of peat soils in the catchments, soils that support plant communities such as buttongrass, melaleuca scrub and rainforest. These soils, and the high degree of vegetative cover, inhibit erosion and nutrient run-off and as a result nutrient and sediment loads delivered to estuaries are generally very low. Some estuaries along the south and west coasts can become totally fresh during winter when river flows are high. During lower flows, a salt wedge re-enters the estuaries, with the tannin-stained freshwater tending to move over the top of the heavier layer of seawater.

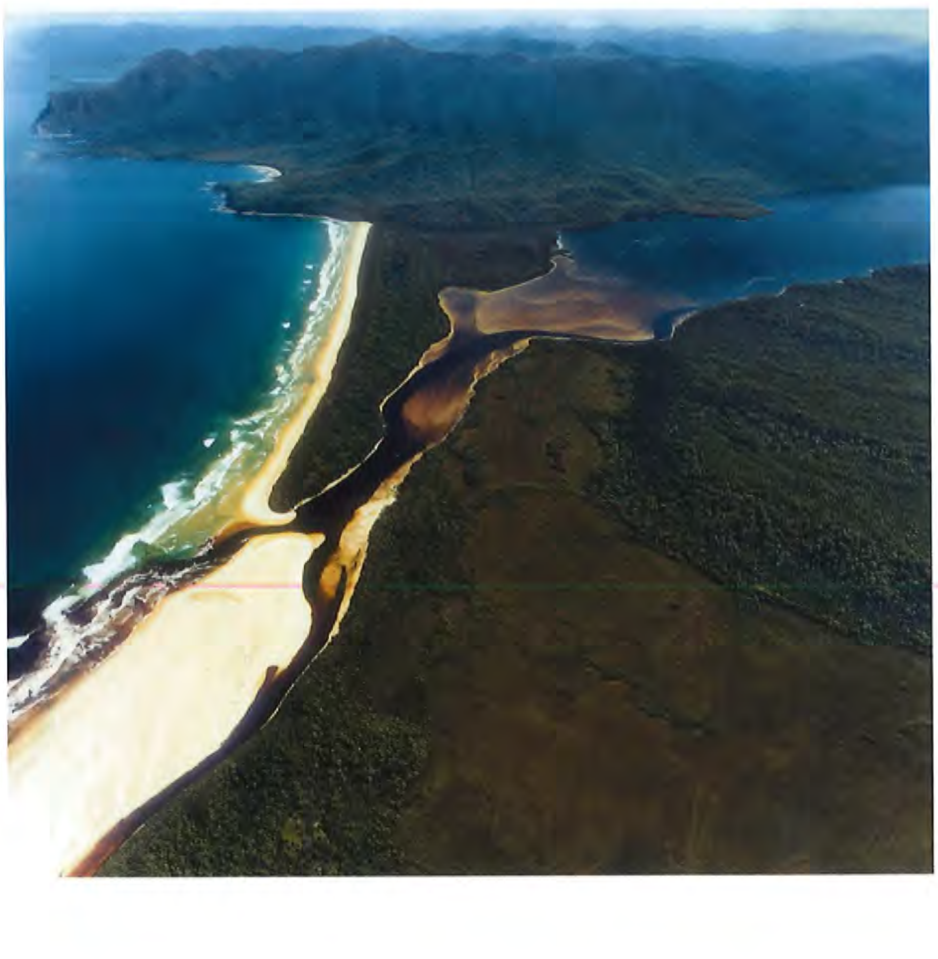
Many species of plant and animal widespread in other estuaries in Tasmania are absent from the southern and western estuaries. Several factors contribute to this. Tannin-stained waters absorb light so little reaches the estuary bed and plant growth here is inhibited. As well, waters flowing into these estuaries have very low nutrient levels. The rocks in their catchments are ancient, with very low levels of minerals left to leach out and there are no human activities in the catchments to introduce impurities into the water.

Backpacker country

The Tasmanian Wilderness World Heritage Area (WHA) is recognised as one of the most outstanding wilderness areas of the world. Only one other site (Mt Taishan in China) has satisfied as many of the criteria for World Heritage listing. It occupies 1.38 million ha (or about 20% of Tasmania) in the rugged southwest of the state. Created amid the controversy surrounding proposed damming of the Franklin River, the WHA has become internationally recognised for its wilderness and recreational values. The cool temperate rainforest, wet sclerophyll forest, alpine, marshland and coastal plant communities are distinctive yet share important connections with the floras of mainland Australia, New Zealand and South America.

Over 1000 km of tracks and trails in the WHA includes some of the best bushwalking in the country, and over 20,000 bushwalkers visit each year. The WHA includes some of Australia's best

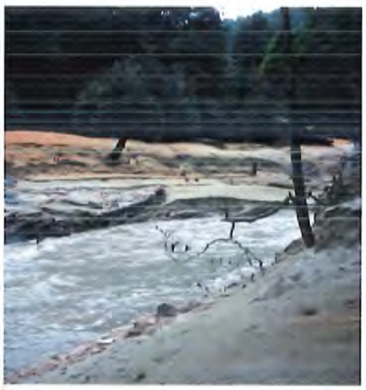
Backpacking in southwest Tasmania with Bathurst Harbour in the background (facing); tea-coloured waters of New River Lagoon, flowing into Prion Bay on the south coast (below, left); Collingwood River (below); hydro dam, west coast (bottom)



known long distance walking tracks, like the Overland (five days), Frenchman's Cap (three days) and the South Coast (seven days) tracks. Whitewater rafting on the Franklin River, caving and lake fishing are also popular. Port Davey and Bathurst Harbour in the remote Southwest National Park provide a rare safe anchorage for commercial fishers and are popular stopovers for sailing vessels and the occasional intrepid sea kayaker.

The Queen River is impacted by residue from the Mt Lyell copper mine (below);

Mt Lyell copper mine, Queenstown (bottom)



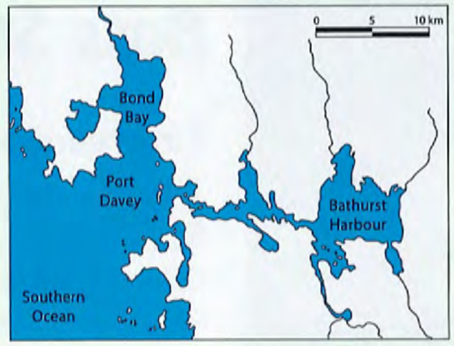
A mining legacy

The entire southwest coast of Tasmania is national park. Further north, grazing occurs in the west coast catchments. The area has a mining legacy that continues to degrade estuarine water quality. Millions of tonnes of mining residues from the Mt Lyell copper mine, near Queenstown, were dumped into the King and Queen rivers. Impacts on downstream areas and Macquarie Harbour continue as highly acidic waters still leach from the mine site. Although mining at Mt Lyell brought employment to thousands and generated considerable wealth, the legacy is a world-scale acid drainage problem.

King River and Macquarie Harbour have also experienced low concentrations of dissolved oxygen as a result of discharge from the John Butters power station. This problem has largely been resolved by including a step in the discharge process which aerates the water, however monitoring of released water is still necessary.

For the time being, the southwest has not been affected by introduced species. As the only region in mainland Tasmania not yet invaded by marine pests, this region must be actively managed to prevent their establishment.

Case study: Bathurst Harbour



Bathurst Harbour is a drowned river valley in one of the remotest corners of the Tasmanian Wilderness World Heritage Area in which unique biotic communities are somewhat protected from the ravages of the 'roaring forties'. It is the only one of Tasmania's drowned river valley estuaries to remain in pristine condition and its inaccessibility makes it an attractive destination for wilderness-based tourism activities such as hiking and sea kayaking. Though remote, the estuary is also popular for boating, providing a spectacular landscape that is sheltered from the most severe ocean swells.

The surface waters of Bathurst Harbour are darkly tannin-stained as a result of leaching from extensive peat soils in the catchment. These tannins prevent much of the light that strikes the surface of the water from filtering through to the estuary floor. Inflowing water is also very low in nutrients and the combination of these features has created a bottom habitat (cold, dark, nutrient poor) suitable for a range of species, such as sea fans and sea whips, normally found only at depths of hundreds of metres in the open ocean. Unlike other estuaries in Tasmania, Bathurst Harbour has a relatively poor complement of molluscs, crustaceans, echinoderms and fish; instead animals such as corals, bryozoans, tubeworms and sponges dominate the community. Several new species have been discovered in Bathurst Harbour and Port Davey in recent years. The main threats to the estuary are from future tourism developments that may be incompatible with the World Heritage values of the region and from increased visitor numbers. Greater boat traffic, particularly of larger vessels, could pose a threat to the unique and sensitive organisms that inhabit the estuary. In 2004, the Tasmanian government declared that the waters of Port Davey/ Bathurst Harbour within the World Heritage Area would be a marine reserve.

Bathurst Harbour

Bass Strait Islands

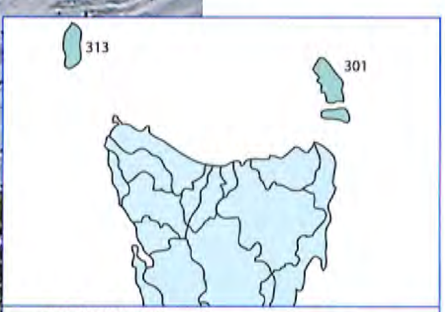
Tiny remote catchments

Climatic influences on King Island in the west and the Furneaux Group (including Flinders and Cape Barren islands) in the east are different. King Island is affected by warmer waters moving across from the Great Australian Bight, including the tail of the Leeuwin current. On the Furneaux Group, the east Australian current is the key oceanic influence, especially during late summer. Strong oceanic influences keep temperature variation relatively low through the year. There are many wet days per year (214 at Currie on west coast of King Island) but despite this, rainfall is relatively low, even compared to adjacent mainland areas. The range is 600 to 800 mm except for the wetter west coast of King Island. Falls are seasonal and estuaries are mainly small and wave-dominated.

King Island cray (above); Millers Bay, King Island (side) (photos this page courtesy Chris and Russell Lee, R.L. Aviation, King Island)

Cheese and wool

On King Island, soldier settlement schemes followed the two world wars. This provided the island with farmers who found the high number of rainy days per year was ideal for raising dairy cattle. Cows can graze all year round and produce excellent milk for cheese manufacture. King Island cheeses, have an international reputation as some of the world's finest.



Bass Strait Island
301 Flinders-Cape Barren islands 313 King Island

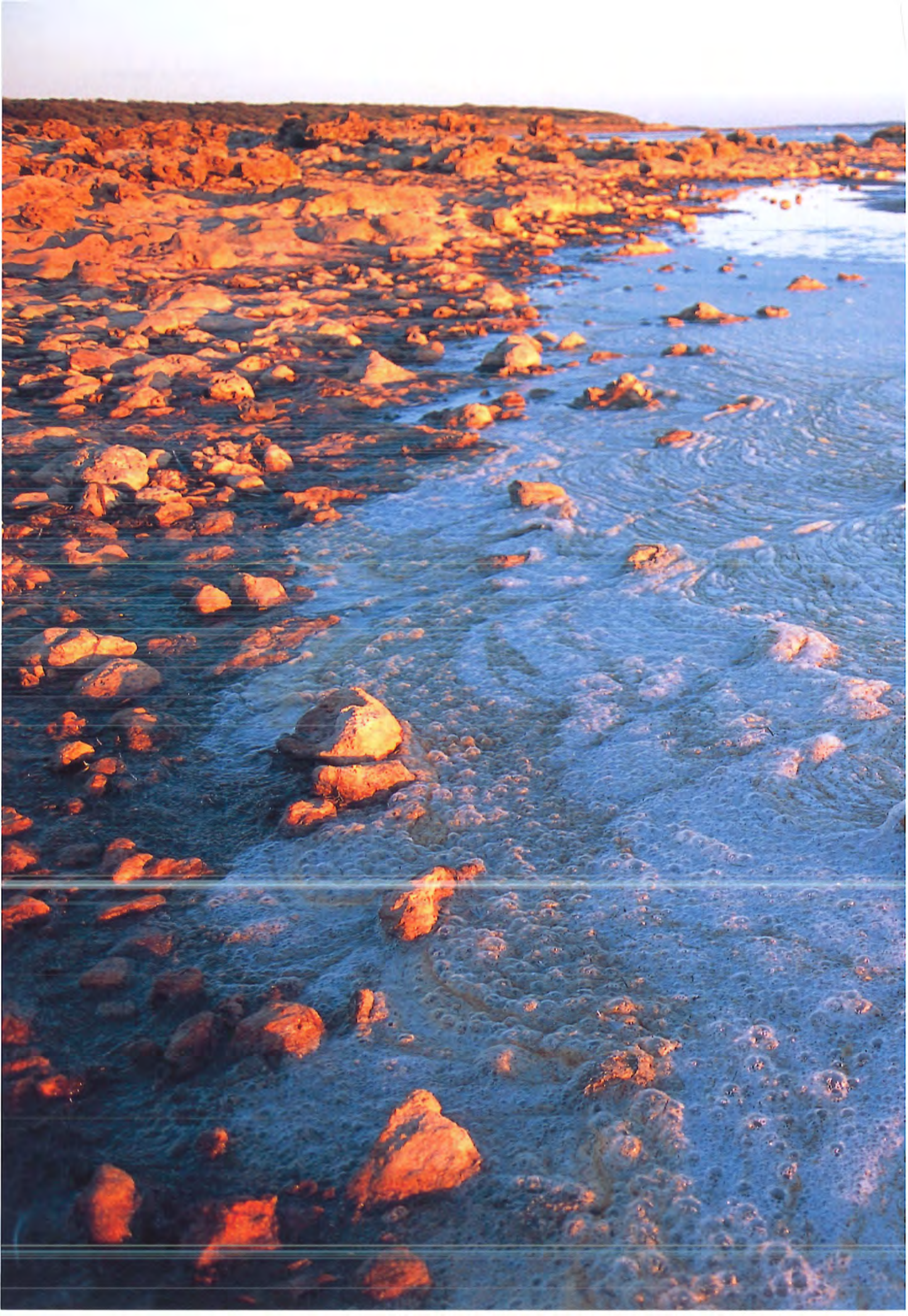
Early European settlement in the Furneaux group included farming on some of the smaller islands and while the farmers later moved to Flinders Island, some still have grazing runs on the smaller islands. Reliable rainfall on Flinders Island provides an ideal environment for sheep grazing. High quality merino wools are used to produce a variety of handmade and hand-knitted products, with value adding on wool production seeing new employment opportunities on the island.

Small population – low impact

The Bass Strait Islands have a low human population. Grazing is the primary land use. Industries are dairying and sheep, kelp harvesting, cray and abalone fishing. King Island is world renowned for cheese and gourmet dairy products. In the past, sealing has been a major industry on both King and Flinders Islands. To date, human impacts on the Bass Strait Island estuaries have been relatively low.

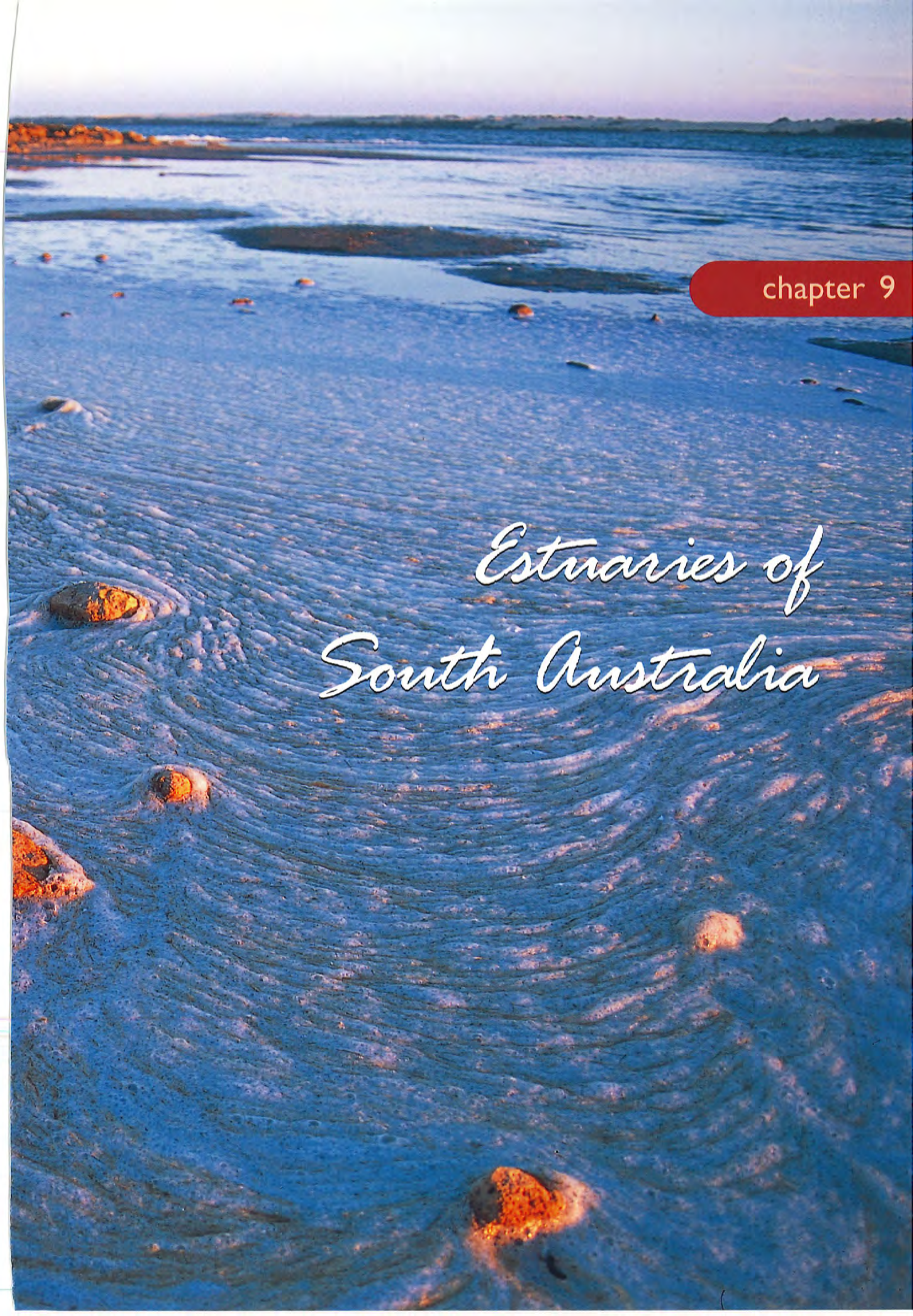
Estuary management in Tasmania

Management arrangements	The management of Tasmanian estuaries is primarily the responsibility of the Department of Primary Industries, Water and Environment (DPIWE).
Key issues	1. Protect ecological and social values of near pristine estuaries 2. Improve water quality in impacted estuaries through improved agricultural, forestry and urban management practices 3. Ensure healthy estuarine ecosystems for sustainable economic (e.g. aquaculture) and socially beneficial (e.g. recreational fishing, swimming) outcomes 4. Manage estuarine and coastal habitats to minimise adverse impacts (e.g. introduced marine pests, seagrass loss)
Key management responsibility	• **DPIWE** provides leadership in the sustainable development and conservation of Tasmania's resources by playing a central role in resource management, industry development, environment protection and conservation of natural and cultural heritage • Various **lead agencies** within DPIWE are responsible for the planning and management of the aquatic and terrestrial environment.
Policy and legislation	Some state legislation relating to the management of Tasmanian estuaries include the: • *Living Marine Resources Management Act 1995* • *National Parks and Reserves Management Act 2002* • *Nature Conservation Act 2002* • *Environmental Management and Pollution Control Act 1994* • *Land Use Planning and Approvals Act 1993* • *Water Management Act 1999* • The **State Coastal Policy 1996** has a central objective of sustainable development of the coastal zone. All activities, uses and developments that may impact on the coast are required to meet the objectives of the Policy. • Under the **State Policy on Water Quality Management 1997**, protected environmental values (PEVs) must be set for all Tasmanian surface waters, including estuarine and coastal waters. PEVs (the current uses and values of a waterway) are being documented in a consultative process involving all interested industry and community groups.
Community initiatives	• Many community conservation and rehabilitation initiatives in and around Tasmanian estuaries have been established under **Tasmanian Landcare Association** programs (**Coastcare**, **Waterwatch**, **Rivercare**, **Bushcare** etc.). The activities undertaken by these groups include water quality monitoring, weed eradication, re-establishment of native flora and fauna, catchment and foreshore management, and the preparation of educational materials. • Over 30 community groups are involved in the **Derwent Estuary Program**, a joint commonwealth, state and local government initiative to restore and protect the Derwent Estuary. • The **Huon Healthy Rivers Project** is an integrated catchment management program involving school and community groups, local forestry and aquaculture industries, in water quality monitoring and Landcare activities. • On the north coast, **Five Rivers Waterwatch** is a community-based water quality monitoring group covering the Rubicon (Port Sorell), Mersey, Don, Forth and Leven rivers.

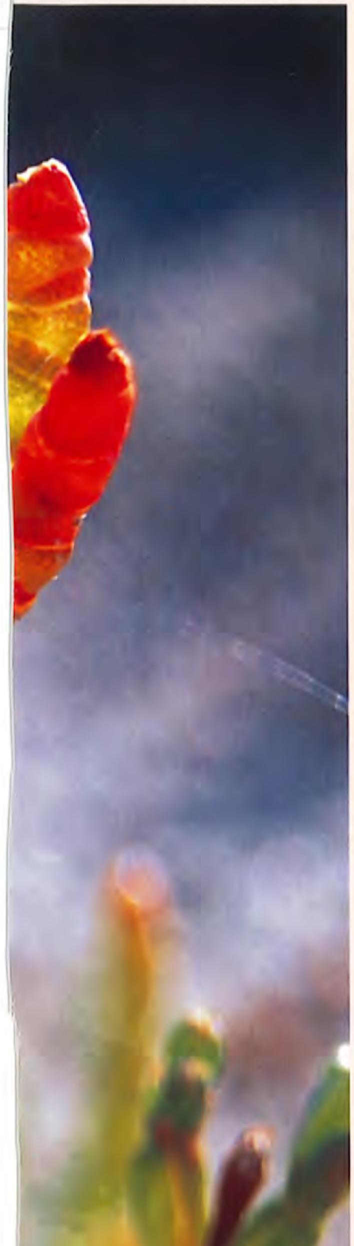


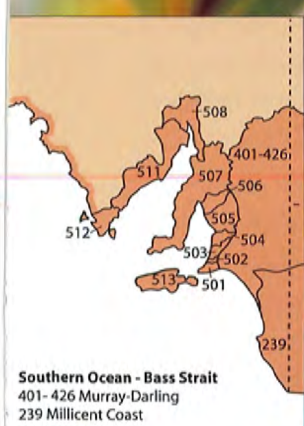
chapter 9

Estuaries of South Australia




Great Aust
Southern Oce
513 Kangaroo
512 Eyre Penin
511 Spencer G
508 Mambray
507 Broughtor
506 Wakefield
505 Gawler Riv
504 Torrens Riv
503 Onkaparin
502 Myponga
501 Fleurieu P





South Australia's climate is arid on the whole. Many of the state's estuaries are coastal lagoons with little freshwater input. Others have small catchments with only periodic river flow into the estuary. South Australia also has several 'inverse' estuaries where salinity increases towards the upper reaches, away from the open ocean. Spencer Gulf and Gulf St Vincent are two of the world's largest inverse estuaries. On the southeast coast of South Australia, the Coorong, Lower Lakes and Murray Mouth form the downstream end of Australia's largest river – the Murray. Catchment and river influences from Queensland, NSW, Victoria and South Australia affect the Murray estuary, and ongoing collaboration is required to manage the estuary of this river system.

There are a myriad of issues facing the estuaries in South Australia. At a state level, South Australia is lacking an estuaries plan/policy to integrate state and local government planning as well as developments occurring within estuaries and their catchments. Such a document is currently being developed and would need to have regard for other plans and strategies that are currently available, for example the Coorong and Lower Lakes Ramsar Management Plan.

The *National Land and Water Resources Audit* identified thirty-seven estuaries in South Australia. These can be divided into six regions listed below.

Regions

- ***Southeast Coast***

  (from Lake George to the southern Coorong Lagoon)

- ***River Murray***

  (Coorong, Lower lakes and Murray Mouth)

- ***Kangaroo Island***

- ***Mount Lofty Ranges***

  (from Inman River to Gawler River)

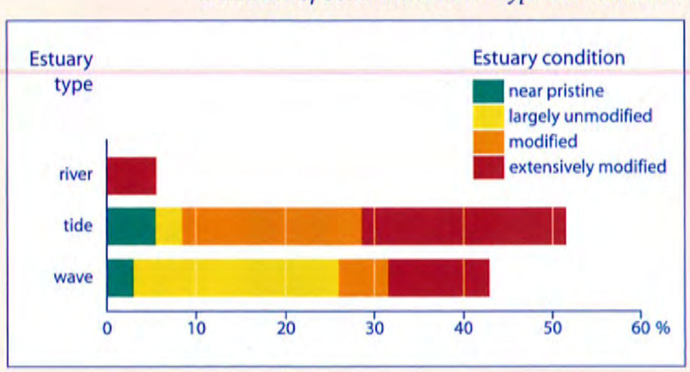
- ***Northern and Yorke Agricultural District***

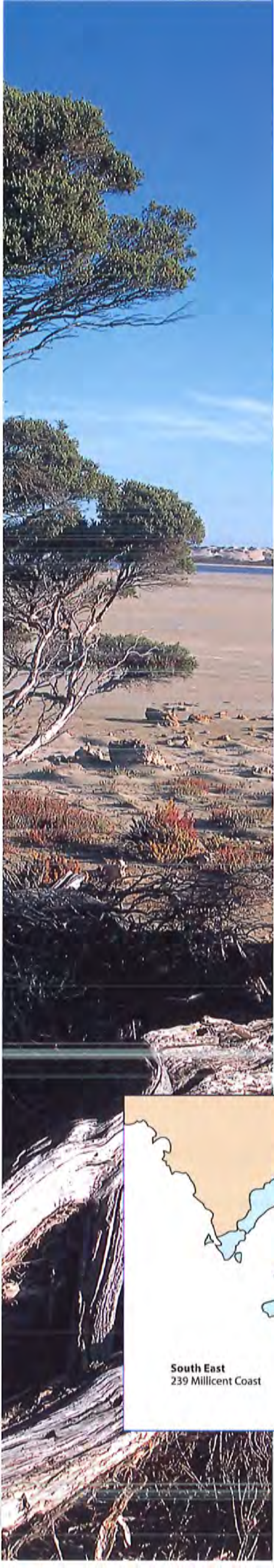
  (from Gulf St Vincent to Spencer Gulf)

- ***Eyre Peninsula***

  (from Franklin Harbour to Tourville Bay)

Estuaries of South Australia – type and condition

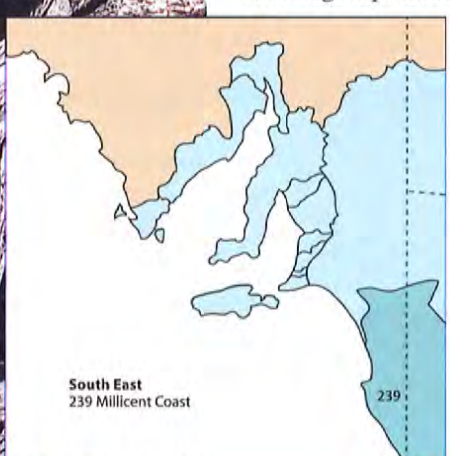




Southeast coast

Pounding waves

From the Victorian Border to the township of Kingston are just a handful of estuaries. They experience a semi-arid climate and winter rainfall. The weather is similar to that of western Victoria, though rainfall decreases toward the northwest. The coast is exposed to some of the highest wave energies in Australia. Land use in this area is predominantly grazing agriculture, horticulture and viticulture and to a lesser extent, timber plantations. Surface waters are managed to mitigate flooding in the area and to provide for the region's wetlands. These wetlands are important in the recharge of two large aquifers underlying the area.



Caves and lobsters

The southeast of South Australia is a unique part of the state with volcanic origins which form many of the area's natural attractions. Naracoorte Caves are a site of a world importance. They contain ancient animal bones – up to 170,000 years old. The caves also have a variety of stalactites, stalagmites and other curious rock formations.

Tourism is the major industry in this region which has a premier food and wine district. Port MacDonnell is the southern rock lobster capital of Australia.

Drained

Estuaries in the region are classified as modified, extensively in some cases. Certain wetland areas in the southeast region have been drained for agriculture. Increased nutrient levels from agricultural and urban run-off and recreational activities have contributed to blooms of toxic blue-green algae and pollution in the waterways and estuaries. In addition increased nutrients caused by polluted groundwater seepage are a threat to some estuary habitats. Land drainage schemes established in the southeast as part of a program to combat dryland salinity in the region have also impacted on the Southern Coorong Lagoon.

River Murray

The Murray meets the sea

The giant Murray-Darling Basin, drains over 1,000,000 km² (14% of Australia) including three-quarters of New South Wales, more than half of Victoria, significant areas of Queensland and South Australia and the whole of the Australian Capital Territory. At the end of the Murray's seaward journey are lakes Alexandrina and Albert, the Coorong (a wetland of international significance) and the Murray Mouth. These sites, once forming the Murray estuary, have huge social, economic and ecological value. The Murray Mouth is a very dynamic system. It migrates in an east-west direction due to river droughts, floods and coastal events. The condition of the Mouth and surrounding estuary serves as a health report card of the entire River Murray.

Many things to many people

Water for three-quarters of Australia's irrigated farmland, domestic water for over 80 percent of South Australia's population in dry years and industrial water for Whyalla, Port Augusta and Port Pirie, comes from the Murray-Darling system. The Lower Lakes are also a source of irrigation and domestic water for surrounding inhabitants. The Murray and its estuary are also major recreation sites for boating, fishing, birdwatching, bush walking and other ecotourism activities.

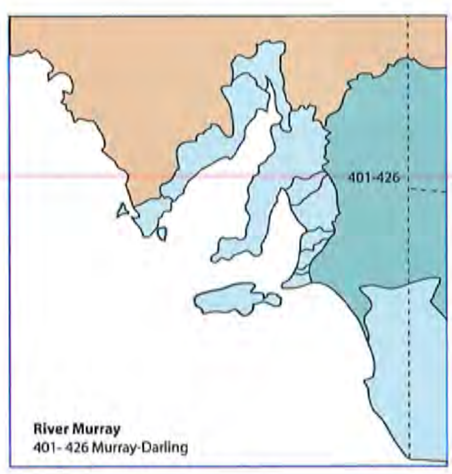
The Ngarrindjeri people view the Coorong and the Murray Mouth as vital cultural and spiritual places – important to the health of their people.

As habitat for species such as mulloway, black bream, greenback flounder and yellow-eye mullet, the Coorong supports recreational and commercial fishing. Outside the Murray Mouth along the beach, Goolwa cockles are harvested. Although not within the estuary, their health and abundance depends on nutrients carried by spring river flows. The yellow-eye mullet is very abundant in the Coorong and is a livelihood for a number of commercial fishers. Ecologically important non-commercial native fish such as the small-mouthed hardyhead also live in the Coorong.

South Coorong lagoon (below); Algae washed up on the shore, Beachport (facing)

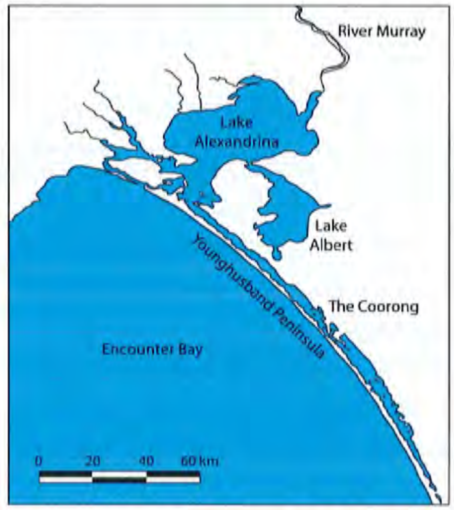
The Mouth closed

In the Murray-Darling catchment, over 100 dams, weirs, locks, barrages and other structures control the river and reduce flow to the Mouth by about 80 percent. These structures have also affected the frequency and duration of flooding essential for many plants and animals adapted to the highly variable conditions experienced in the Murray and its estuary. The taking of water and the construction of the barrages has altered the Murray estuary. In 1981, for the first time in recorded history, the Mouth closed. This closure has serious implications for the health of the Coorong.



It is an elemental region, a place of wind and water and vast skies, of sandhill and tussock, lagoon and waterweed, stone and scrub. It is a place of softened contours, muted colours and sea haze – and of glaring saltpans so intense that our brows pucker and our eyes wince. A place of winter storms and summer sunglades, of shorelines soft with sand and sibilant reeds, and of limestone outcrops sharper than teeth. A place to sense the universal in the particular, the infinite in the infinitesimal, the verities of life in blowing seeds and grains of sand.

Colin Thiele, *Coorong*



The historical estuary of the River Murray – lakes Alexandrina and Albert, the Coorong and numerous channels in the Murray Mouth, formed a huge area covering over 75,000 ha. Here water from the vast Murray-Darling Basin mixed with seawater from the Southern Ocean. The northern Coorong and Lower Lakes have been altered dramatically since settlement, mainly due to the enormous demand for water from the River Murray upstream and the construction of the barrages.

In the late 30s and early 40s five barrages were built to separate fresh- and saltwater and provide gravity-fed irrigation and domestic water from the lakes. Saline water once extended as far as 250 km upstream from the Murray Mouth during times of low flow. As a consequence of barrage construction, the area of the Murray estuary has been reduced by 90 percent. Now the Lower Lakes and lower river reaches of the Murray are permanently fresh water. Below the barrages and into the Coorong – the long, narrow lagoon separated from the Southern Ocean by Younghusband Peninsula – salinity is increasing as a result of reduced freshwater flows. The ecology of the Coorong and Murray estuary is further impacted by the inappropriate timing of freshwater releases from the Lower Lakes through the barrages.

The barrages have reduced fish populations and species diversity in the Murray estuary. Reduced flows at the Mouth have restricted the migration of fish species from the ocean and the barrages act as a barrier to migration further upstream for fish that

breed and grow in the fresher river water. The barrages have also greatly reduced habitat for bird life. The Coorong is a summer refuge for migratory birds. It supports the world's largest breeding colony of Australian pelicans. The area is listed under the Ramsar Convention as a Wetland of International Importance and is included on the register of the National Estate. More than 240 species of birds have been recorded here and many of the migratory birds are protected under the international agreements of CAMBA and JAMBA. A steady decline in visiting wader numbers has occurred since the construction of the barrages. This is due, at least in part, to the water in the Lower Lakes and adjacent wetlands being artificially maintained at a relatively high level and a lack of freshwater input into the Coorong. In the Lower Lakes it has also led to severe shoreline erosion from wind waves, made worse by grazing and clearance of vegetation.

Photography supplied by MAPLAND Environmental Information, Department for Environment and Heritage

The ecology of the southern Coorong has also been altered as a result of numerous land-drainage schemes in the southeast which have decreased the flow of freshwater into this part of the system. After many years of adaptation to this reduced freshwater flow and hypersaline conditions, the Upper South East Drainage Scheme has been established which will discharge water from groundwater drains into the southern Coorong lagoon via Salt Creek. The goal of this drainage scheme is to assist in combating dryland salinity in the southeast region. Salinity within the Coorong varies from seasonally fresh or brackish near the Murray Mouth to extremely hypersaline in the southern lagoon. The plants and animals in the Coorong are adapted to survive in this highly variable saline environment, however with the addition of less saline groundwater, there is potential to disrupt the ecological balance in the lagoon.

The Murray Mouth (top), sea foam on the Coorong (above), Coorong saltmarsh (below)

Other threats to the Coorong include weed invasion, feral animals, degradation of sand dune plant communities by off-road vehicles and campers, boating and water-skiing. The Coorong and Lower Lakes Ramsar Management Plan has been developed for the region and there is also a Coorong National Park Management Plan to tackle the numerous issues facing the important Murray estuary.

Kangaroo Island

Sea lions, penguins, sharks and abalone

Kangaroo Island is Australia's third largest island after Tasmania and Melville Island (NT). It has low to moderate rainfall, mainly in winter (500 to 900 mm per year, increasing from east to west). Most Kangaroo Island estuaries are small in size with the exception of the American River estuary – part of a coastal lagoon. The estuaries of Kangaroo Island function in diverse ways with significant tidal and wave energy. The southern extent of the island is exposed to high wave energy from the Southern Ocean. Very few streams run to the coast with most run-off disappearing into the porous limestone and sand soils. Hence, many Kangaroo Island estuaries are temporal depending on the season.

Wildlife sanctuary

Approximately a third of Kangaroo Island is protected within the Flinders Chase National Park and the adjacent Ravine des Casoars Wilderness Protection Area. The national park presents striking coastal landscapes, diverse shrub and woodland communities with many endemic species and an abundance of highly visible wildlife. Tall limestone cliffs dominate the windswept western coastline. Visitors can explore many walking tracks within the park. Wildlife to watch includes sea lions, fur seals, sea eagles, black cockatoos and various small- to medium-sized mammals. Flinders Chase came to be seen as a sanctuary for threatened species from the mainland due to the absence of

Fur seal pups, Kangaroo Island

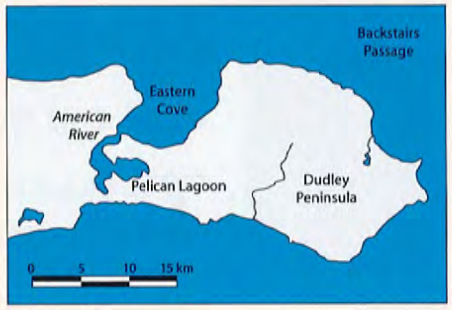
foxes and rabbits on the island. Two rivers, the Rocky and Breakneck, are completely protected within the park with Breakneck River estuary ranked as near-pristine.

Kangaroo Island
513 Kangaroo Island

Tourism and fishing

Grazing of sheep and cropping are the main land uses elsewhere on Kangaroo Island. Tourism, mostly nature-based, is now also a major industry on the island. With the island's estuaries varying in their status from largely unmodified to modified, tourism may be a useful tool for encouraging the protection of these regions.

Case study: Pelican Lagoon/American River



The entrance of the piece of water at the head of Nepean Bay is less than half a mile in width, and mostly shallow; but there is a channel sufficiently deep for all boats near the western shore. After turning two low islets near the east point, the water opens out, becomes deeper, and divides into two branches, each of two or three miles long... There are four small islands in the eastern branch; one of them is moderately high and woody, the others are grassy and lower; and upon two of these we found many young pelicans, unable to fly. Flocks of the old birds were sitting upon the beaches of the lagoon, and it appeared that the islands were their breeding places; not only so, but from the number of skeletons and bones there scattered, it should seem that they had for ages been selected for the closing scene of their existence... I named this piece of water Pelican Lagoon.

Matthew Flinders

Like many estuaries in the more arid parts of Australia's coastline, the Pelican Lagoon/ American River system is not 'typical' – it has very little freshwater input. The 'estuary' consists of a large shallow (<2 m) lagoon with several islets, connected to the sea by a narrow channel known as American River. A number of freshwater soaks run into the lagoon and the American River channel collects some freshwater flow from several small creeks. Extensive tidal flats within the estuary system are colonised by seagrass, such as *Posidonia* and *Zostera* species. A number of commercial and recreational fish species including King George whiting, yellow-eye mullet, salmon trout, garfish and Australian herring use the estuary, and the seagrass beds in particular, as a nursery area. Pelican Lagoon is a dedicated aquatic reserve. It is an important refuge and breeding habitat for many invertebrates, fish and both permanent and migratory water-birds, as well as being important for local dolphin pods. Sponge communities typical of deeper waters also occur in areas of the lagoon. This is probably due to the natural turbidity of the area providing sponges with sufficient food to filter feed.

The American River township is a focal point for the growing tourism industry on Kangaroo Island, based upon the attractions of the natural environment. The beauty of the area and passive viewing of wildlife, such as dolphins and waterbirds, are reasons for visiting Pelican Lagoon but motorised vessels have contributed to some habitat disturbance in the river including seagrass loss. Another threat is the increasing salinity and drying up of freshwater soaks that flow into the lagoon. This threatens birds, such as musk duck, that rely on these soaks as a freshwater source for their young.

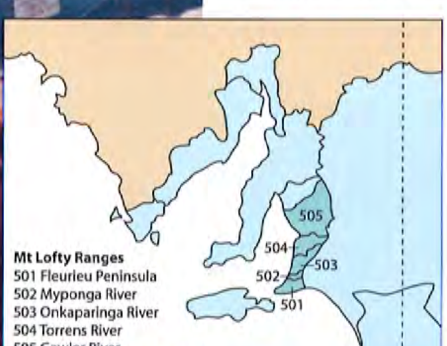
Mount Lofty Ranges

Cool and moist

The Mount Lofty Ranges form the backdrop to the city of Adelaide and consists of a range of hills about 150 km long and about 35 km wide. This covers an area of some 5300 km^2, extending from Cape Jervis in the south to the Barossa Valley in the north. It includes one of the few higher rainfall (over 900 mm) areas in South Australia, has a cool climate and fertile soils and contains unique flora and fauna. An extensive port established on the Port River-Barker Inlet estuary services the city of Adelaide. The Barker Inlet, St Kilda and Port Gawler region have been identified as Wetlands of National Importance with a population of bottle-nosed dolphins residing in the Port River. The estuary is a maze of tidal creeks, mudflats, dense mangrove forests, saltmarshes, seagrass meadows and open water, which is home to many species of marine plants, fish, invertebrates and seabirds, all with 95 percent of South Australia's human population on its backdoor.

Adelaide's watershed

The Mount Lofty Ranges supply over 60 percent of the water for Adelaide, a capital city of around one million people. This region also yields over $240 million of farm gate value in agricultural produce and is a prime recreation and tourism area for South Australia.



The special natural features of the region, combined with its proximity to a capital city, have created a complex environment with a large and often conflicting range of land uses and immense development pressures.

Ports and industries

Estuaries in the Mount Lofty Ranges-Barker Inlet/Port River, the Gawler, Onkaparinga, Myponga and Inman rivers are all extensively modified. The Barker Inlet/Port River region has seen major disturbance from the building of port facilities and industry development.

Heavy metals from these activities accumulate in plants and animals, for example, exceptionally high levels of mercury have been found in the Port River dolphins. Other estuaries in the region have also been affected by altered river flow patterns and water abstraction, reducing the amount of freshwater draining into the estuaries.

The Onkaparinga River estuary (the third largest estuary in area in SA and home to a number of threatened bird species) has been altered by the construction of the Mount Bold reservoir upstream of the estuary in the Onkaparinga catchment. Freshwater flows to the estuary have reduced and sedimentation has increased. This popular recreation site is also impacted by off-road vehicle use and illegal rubbish dumping.

Case study: Barker Inlet/Port River

The Barker Inlet/Port River Estuary is the largest coastal wetland ecosystem in Gulf St Vincent – an important nursery and feeding area for many recreational and commercial fish and crustaceans in the gulf. Despite its proximity to Adelaide, it is an area of international significance for waterbirds, shorebirds and seabirds. It provides a habitat for a diversity of invertebrate and fish species. The estuary is home to a population of bottle-nosed dolphins (*Turiops truncatus*). The presence of these dolphins, living so close to the heart of a city with over a million people is thought to be internationally unique. The Barker Inlet Aquatic Reserve supports the world's southern-most stand of grey mangrove (*Avicennia marina*).

Since European settlement the area has been extensively modified by a range of uses including the building of port facilities, sewage disposal, stormwater run-off, industrial development, land reclamation, recreational use and litter. The effects on the Barker Inlet and Port Adelaide estuary include poor water quality, nutrient and sediment related loss of seagrass and mangroves, heavy metal contamination of sediments and algal blooms.

A Barker Inlet Port Estuary Committee was formed to address the management issues of this estuary of state, national and international significance. A major focus is integrated management to arrest the declining ecological health of the area. Projects addressed stormwater and gross pollutants, monitoring water quality and protecting dolphins and the area's unique and valuable wetlands. The South Australian government has committed to enact legislation for an Adelaide Dolphin Sanctuary. The act aims to protect the dolphins and their habitat while accommodating the range of estuary users.

Port River

Northern and Yorke District

Extensive inverse estuaries

This region contains two large gulfs, Gulf St Vincent to the east and Spencer Gulf to the west; situated between the eastern Fleurieu and western Eyre peninsulas and separated by the long, narrow Yorke Peninsula. Catchments in the gulfs have a semi-arid to arid climate. Rain mainly falls in the winter, in relatively predictable showers, making wheat growing possible. Annual rainfall is highest at the southern tip of Eyre Peninsula (about 625 mm near Port Lincoln) while the Adelaide area receives about 500 mm. Rainfall generally decreases northward, and the rest of the area receives around 250 to 400 mm per year. The influence of waves versus tides varies along the length of the gulf estuaries. Wave energy dominates the southern end of the gulfs and tidal energy in the northern reaches where extensive tidal flats have formed. The Onkaparinga River estuary (Mount Lofty) is one of the few in South Australia where river energy is significant.

Massive seagrass meadows, dominated by *Posidonia*, form a significant habitat for much of South Australia's commercial and recreational fisheries. Vast, low-lying, areas above the tides include some of the largest temperate samphire, mangrove and saltmarsh communities in Australia. Only one mangrove species, *Avicennia marina*, grows in South Australia, mostly within sheltered gulf waters. *A. marina* provides important breeding areas for a variety of birds such as cormorants. Seabed flora and fauna of Upper Spencer Gulf have a distinct remnant tropical element. The area has been identified as a distinctive marine bioregion (the Northern Spencer Gulf Bioregion).

Northern Yorke Agricultural District
506 Wakefield River
507 Broughton River
508 Mambray Coast
511 Spencer Gulf

*Seagrass meadows in the Gulfs region (*Posidonia sp.*)*

Cleared and urban catchments

Many popular and historic holiday towns are located along the gulfs. During summer, townships such as Port Vincent, Port Victoria, Edithburgh, Stansbury, Port Neale, Tumby and Arno Bays, to name but a few, are crowded with visitors enjoying the variety the gulfs offer. Attractions are the history, beaches, scenery, companionship and fishing. During the 19th century and until the Second World War, the gulf towns were the destination of sailing ships transporting wheat and wool back to Europe. Wheat from South Australia's gulf ports was the last viable trade for ships under sail. Many relics of this maritime past can be found in the towns and on several wrecks in Spencer Gulf.

Catchments in the gulfs region are some of the most extensively cleared in Australia, with land use dominated by grazing and dry-land agriculture (wheat). Soil is lost to wind and water erosion leading to increased sediment and nutrient loads in rivers and estuaries. All of the estuaries in the gulf areas are modified, some extensively. Port Pirie is home to the largest smelter of lead in the world which over the past 100 years has been discharging cadmium, lead and zinc into the marine environment. Very high levels of historic lead still remain in the marine sediments. Industrial effluent (including discharge from the lead and zinc smelter) is associated with seagrass loss in First Creek. Port Pirie also has run-off and discharges from shipping, urban development, sewage treatment works and heavy industrial development. In northern Spencer Gulf, water quality is affected by port facilities, a sewage treatment plant, septic systems, power stations and urban run-off from Port Augusta.

Cuttlefish in Upper Spencer Gulf (below); Port Augusta tidal creek (bottom)

Eyre Peninsula

Arid catchments meet raging seas

The Eyre Peninsula stretches 1000 km from Whyalla in the east to the Western Australian border and from the Gawler Ranges in the north to Port Lincoln 400 km to the south. The region is known for its 2000 km of ruggedly beautiful coastline. Estuaries from the southern tip of Eyre Peninsula and westward are characterised by an arid climate with some winter rainfall, generally brought by cold fronts from the southwest. Only minor surface flows occur although groundwater seepage may be considerable. The eastern half of the region has a small number of estuaries. Tidal energy dominates. In the west is the Nullarbor Plain, a limestone plateau raised 50 to 200 m above sea level joining the Great Australian Bight as a line of cliffs. Surface run-off is essentially nil in this area, as the limestone ensures any rainfall soaks straight downwards. The most western occurrence of the mangrove *Avicennia marina* in South Australia is at Davenport Creek in Tourville Bay west of Ceduna.

Grain and sand

The Spencer Gulf borders the east of the Peninsula along which are a number of small coastal towns with sandy beaches and excellent fishing opportunities. In contrast to the sheltered waters of the Spencer Gulf, the west coast is exposed to the full force of the Southern Ocean. The hinterland of the Eyre Peninsula boasts picturesque hills, vast grain growing tracts and agricultural areas – producing over 10 percent of Australia's wheat.

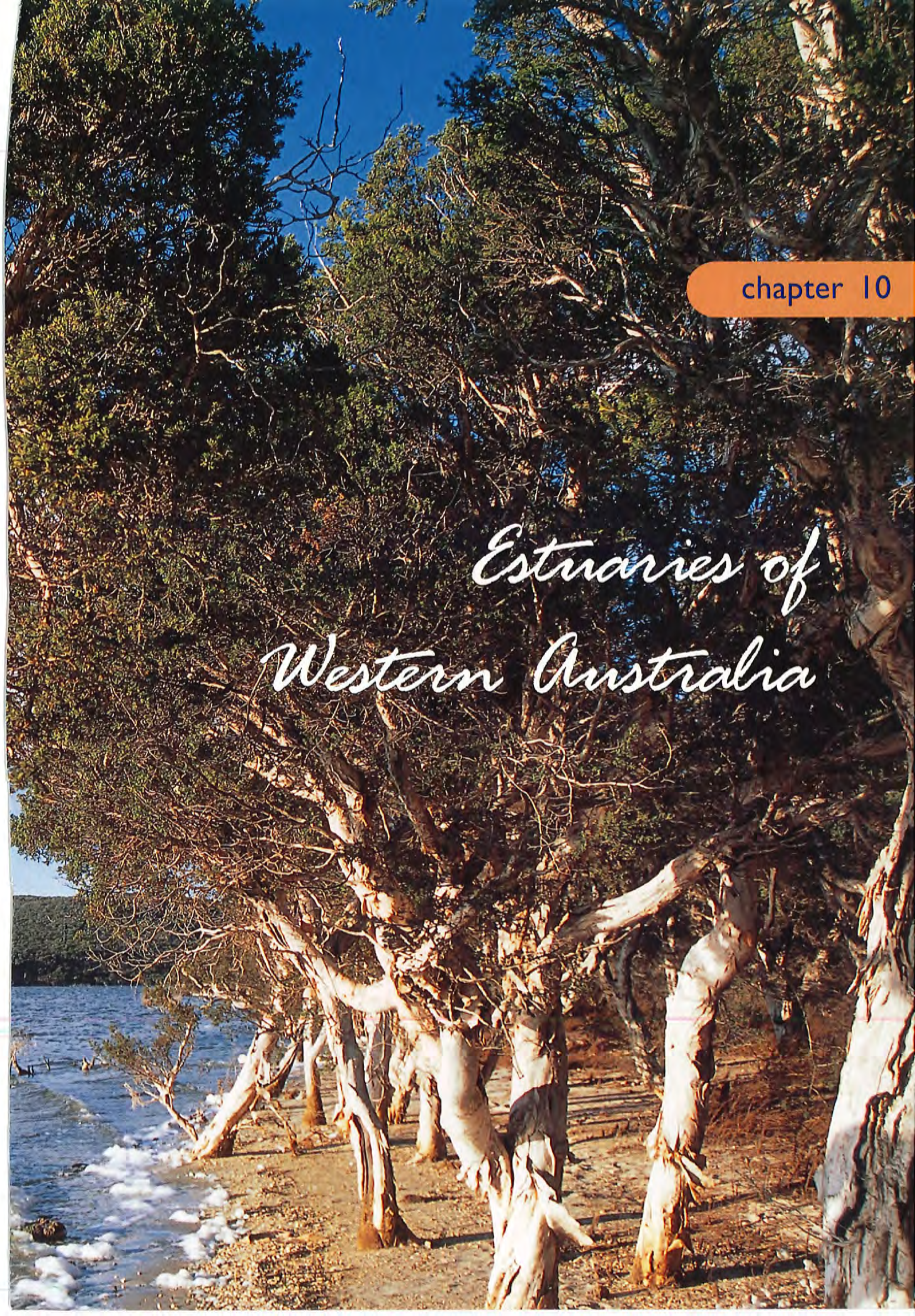
Oyster racks at Coffin Bay, Eyre Peninsula

Grazing, cropping and oyster aquaculture

Grazing sheep and wheat cropping are the main land uses. The estuaries and coastal lagoons of the region range from near-pristine to modified. Physical disturbance such as off-road vehicle use, stock grazing, catchment clearance and oyster aquaculture has had an adverse influence on some estuaries in the Eyre Peninsula region.

Estuary management in South Australia	
Management arrangements	Estuarine management and data collection is within the scope of several state departments, catchment water management boards and local government councils, with no one central organisation coordinating an estuaries program.
Key issues	The need for a lead agency/policy to coordinate estuarine management in relation to marine and coastal initiatives and direct links with terrestrial management via Integrated Natural Resources Management.
Key management responsibility	• The **Coast and Marine Branch (CMB)** in **the Department for Environment and Heritage (DEH)** is responsible for the implementation of the Marine and Estuarine Strategy for South Australia *Our Seas & Coasts* (1998). The CMB has prepared a report for the Coast Protection Board entitled "The Status of South Australia's Estuaries: a proposal for a State Estuary Program". An Estuaries Project Officer has also been employed by the CMB to coordinate the development of Estuaries Policy for South Australia in partnership with other agencies and the Coast Protection Board. • **National Parks and Wildlife (DEH)** is responsible for regulatory activities within estuaries that occur in National Parks. • **Department of Water, Land and Biodiversity Conservation (DWLBC)** has main jurisdiction for water quantity allocations as well as for the management of the River Murray. • The **Environment Protection Agency (EPA)** has developed the Environment Protection Policy on Water Quality including marine, estuarine and freshwater resources. • **Primary Industries and Resources SA (PIRSA)(Fisheries)** manages the fisheries associated with all estuaries in SA. • **PIRSA** (including the **South Australian Research and Development Institute-SARDI**), and **SA Water** (including the **Australian Water Quality Centre – AWQC**) are involved in estuarine monitoring including fish surveys, water quality, eutrophication and algal blooms.
Policy and legislation	• The **Marine and Estuarine Strategy, Our Seas & Coasts** • **State Water Plan 2000 –** includes an action for the development of estuaries policy for South Australia • Legislation that impacts on estuaries in SA: ***Coast Protection Act 1972, Water Resources Act 1997, Local Government Act 1999, Development Act 1993, Fisheries Act 1982, Soil Conservation and Landcare Act 1989*** • **Other site specific plans:** **Coorong National Park Management Plan** **Coorong and Lower Lakes Ramsar Management Plan**
Community initiatives	There are a number of community groups active in estuarine initiatives. These include urban and regional **Waterwatch** groups, **Our Patch**, the **Barker Inlet and Port Estuary Committee**, the **Middle Beach Education Centre** and the **Southern Fleurieu Catchment Resource Centre Marine Education Program.**

Estuaries of Western Australia




Pilbara and Subtropica
West Coast
701 Greenough River
702 Murchison River
703 Wooramel River
704 Gascoyne River
705 Lyndon-Minilya Riv
706 Ashburton River
707 Onslow Coast
708 Fortescue River
709 Port Hedland Coast
710 De Grey River
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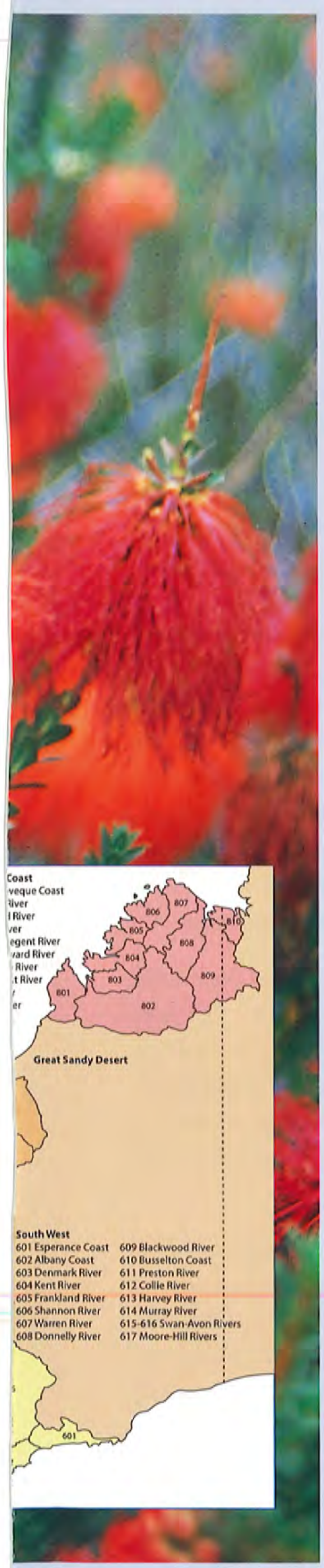


Western Australia is a vast, dry state with great diversity in its estuaries. At one extreme are tropical systems with huge tides, such as the Kimberley, at the other, the temperate, wave-dominated lagoons of the southwest and south coast (where tide range is small). Rainfall and discharge vary across the state and from year to year. Relatively high and consistent freshwater flows occur only in the far southwest. Many estuaries drain large areas that for years contribute little to flows but are capable of channelling huge floods when catchment rainfall is widespread.

The ecology of estuaries in the Kimberley and Pilbara regions is poorly understood, however, several of the estuaries in the southwest and south coast regions have been well studied, especially where nutrient-related algal blooms have occurred. Many of these southern estuaries open and close at different times of the year, often unpredictably. This strongly influences ecology and is a problem for managers as there is no 'average' condition for these systems. Rising groundwater has pushed salty water into estuaries in catchments affected by dryland salinity.

In many cases, catchment impacts have not yet lead to estuary decline. This difference between catchment condition and estuary condition is probably due to the time lag between major problems in the catchment and decline in estuarine ecosystems. The very slow movement of groundwater to the estuary also contributes to this time lag between causes and effects. Because of the delay, restoration efforts may not show fast improvement in estuary condition. Over-use of groundwater has caused losses of *Melaleuca*, riparian vegetation and critical estuarine habitat. Drainage has seriously compromised wildlife habitat (e.g. in Peel–Harvey estuary).

Regions

- ## *South Coast*
  (from Barker Inlet to Hardy Inlet)
- ## *South West*
  (from Margaret River to Swan-Canning)
- ## *Mid West Coast*
  (from Moore River to Giralia Bay)
- ## *Pilbarra*
  (from Ashburton to Banningarra Creek)
- ## *Kimberley*
  (from Jaubert Creek to Ningbing Range creeks)

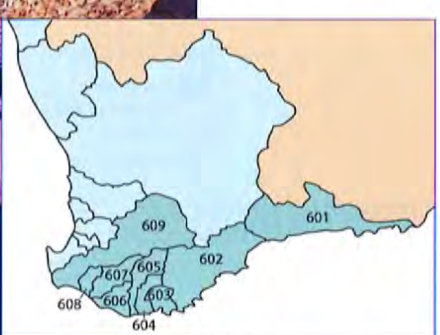
Estuaries of Western Australia – type and condition

South Coast

Unpredictable habitat

Most south coast estuaries are shallow lagoons, opening to the east of headlands that give shelter from southerly ocean swells along the narrow, fragmented coastal plain. The area from Albany west to Cape Leeuwin is a relatively high rainfall (1000–1600 mm) band. From Albany to Esperance rain drops off and becomes less predictable. Magnitude of freshwater flows is determined more by position on the coast (i.e. whether in the high or low rain area) than catchment size, as upper catchments are mostly semi-arid. Most estuaries in the high rain area are seasonally open (Walpole–Nornalup is permanently open); most east of Albany are normally or permanently closed.

Princess Royal Harbour is a marine bay near Albany with a deep permanent entrance and little direct flow, whereas Oyster Harbour has a narrow permanent opening and receives the flow from four rivers. Wave energy drops east of Albany where the coast faces away from the dominant swell direction. Some of the inlets are sheltered by nearshore reefs. Bar opening is unpredictable, depending on a combination of tides, freshwater flows and weather. In this area, increases in water level from atmospheric low pressure are important in inundating shore areas and overflowing bars when water levels are high. In addition to winter rain, deteriorating summer cyclones and thunderstorms from the north can bring unseasonal downpours, break entrance bars and open estuaries to the sea.



South Coast
601 Esperance Coast 602 Albany Coast 603 Denmark River 604 Kent River 605 Frankland River 606 Shannon River 607 Warren River 608 Donnelly River 609 Blackwood River

The frequency of bar opening influences the ecology of south coast estuaries. With entrances closed, water level and salinity vary with freshwater flow and evaporation. Salinity can vary from almost fresh to much saltier than seawater. Lagoons may even dry up completely. Temperature variation is also extreme and many of these estuaries have dark, tannin-stained water. The highly variable physical environment limits the number of species that can survive. As the frequency of bar closure increases, species diversity drops. Initially this is due to limitations on recruitment from the sea and eventually to extremes in salinity and temperature.

Most south coast estuaries are dominated by a few species that tolerate variation in saltiness and temperature throughout the year. The seagrass *Ruppia megacarpa* can grow under a wide range of salinities and is readily spread by waterbirds. It is common in these estuaries.

Oyster and Princess Royal harbours have richer animal and plant communities, including seven seagrass species. Saltmarsh is common in south coast estuaries, though in lagoons that are normally closed to the sea, water level fluctuations and hyper-salinity restrict the establishment of saltmarsh. Above the tidal influence, fringing melaleuca forests are common.

Scenic coastline

The scenic coastline around Albany has high aesthetic, tourism, and biodiversity values. The Torndirrup National Park captures much of this spectacular coastline of granite headlands, small bays and beaches. Further west, Karri forests run to the edge of estuaries and coastal heaths with a high diversity of plant species fringing the shorelines. The rugged coast throughout the region extends well beyond Esperance offering picturesque beaches, wide vistas and numerous fishing opportunities especially at the mouths of estuaries. The Fitzgerald National Park and World Biosphere Reserve protects a large area representative of pre-settlement condition including undisturbed estuaries such as the Hamersley and the Fitzgerald.

Rising saline water tables

The south coast is a fragile region with high conservation values and problems of wind and water erosion, rising saline water tables and waterlogging. The area has incredibly high plant diversity, containing about one-third of the state's plant species. Salinity is a major problem on the wheatbelt portion of these catchments. Vast areas of agricultural land may be affected within the next few decades. Development in this region has mainly occurred in the past 50 years, centering on sheep, cattle and cereal crop production, with more recent increases in horticulture, forestry and viticulture. Many catchments have been mostly cleared, and nutrient enrichment and infilling of shallow estuarine basins with sediment from degraded catchments are major issues.

East of Albany

Typically, estuaries east of Albany open infrequently, for a short period and at unpredictable times. Rising water tables in over-cleared catchments have resulted in more rapid run-off, which is starting to change the frequency of bar openings. Culham Inlet, for example, reputedly opened once in the last century. It has opened three times in the last 10 years. Clearly, changed hydrology is having a severe effect on the estuary. Most catchments are heavily cleared and salt-affected with associated estuaries showing signs of stress, especially the Beaufort, Gordon and Wellstead estuaries.

Sedimentation is a major issue in estuaries on this coast. In the central part, the Fitzgerald National Park and World Biosphere Reserve have outstanding natural values. Fitzgerald, Hamersley and St Mary's Inlet lie within the park. Stokes Inlet is also in a national park though estuarine values were not the reason for protection. Oldfield estuary is still near-pristine, despite upper catchment clearing. Much riparian vegetation remains along the river. In general, estuaries along this coast are not well studied or understood. Their high tourism potential creates development pressures. Large-scale mining for nickel, tantalite, and silver lead is a new pressure in the Ravensthorpe Range which is rich in plant life.

Fringing vegetation, Stokes Inlet

West of Albany

In the high rainfall area west of Albany, the lower catchments deliver most of the freshwater flow to estuaries. They range from well-forested (mostly state forest) to heavily cleared. Some catchments are being logged. The upper catchments are geologically distinct and in general are heavily cleared for agriculture. Broke Inlet is at the mouth of the Shannon River and located entirely within the d'Entrecasteaux National Park. It is the only estuary on this section of coast in near-pristine condition. As well as having high conservation values, Broke Inlet is a useful benchmark with which to compare the effects of nutrient enrichment and sedimentation along the south coast.

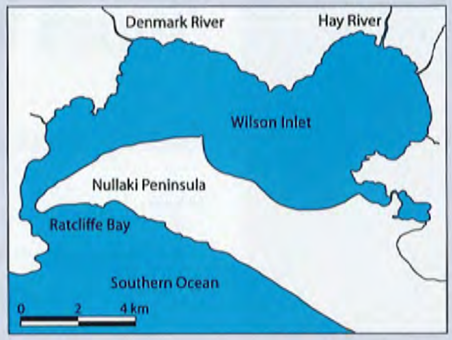
Two Peoples Bay on the south coast of Western Australia

Other estuaries west from Walpole–Nornalup are only slightly modified. About half of the Walpole–Nornalup catchment is forested and good riparian vegetation remains on the lower stretches of the rivers. In the Scott coastal plain that runs into Hardy estuary, intensive horticulture such as potato growing, and more recently, dairying, contributes high nutrient loads to the estuary. The catchments of the smaller estuaries between Walpole and Albany have various degrees of clearing but in general are still in good condition. Even Wilson Inlet, which has increased phytoplankton and marine plant and growth, is still in good condition. The bar here is artificially opened and closes naturally on an annual basis.

The eastern portion of Wilson Inlet and the neighbouring Torbay catchment are drained to prevent waterlogging. Sandy soils and high nutrient loads in the shallow waters of these systems have produced blue-green algae blooms during summer months. Torbay inlet, which is artificially opened for brief periods in the summer, is now subject to *Nodularia* blooms. The Princess Royal and Oyster harbours, have been actively managed since major seagrass declines in the 1980s resulting from eutrophication. An attempt to harvest the prolific algal growth was unsuccessful. Reduction of point sources in Princess Royal Harbour has greatly reduced the nutrient loading but little progress has been made in reducing nutrients flowing from the extensively cleared Oyster Harbour catchment.

There is limited commercial fishing along this coast, but gillnet fishing for mullet, King George whiting, flathead, herring, cobbler and garfish is common with Wilson Inlet recording the highest catches. Several of these estuaries are highly productive (due to human-induced nutrient pollution and increased marine exchange).

Case study: Wilson Inlet



Wilson Inlet is a shallow, 'bar-built' estuary adjacent to the town of Denmark (population 1978) on the Denmark River. It is an important recreational and scenic resource and supports a significant component of the south coast commercial fishery. Fringing swamps form important feeding and roosting areas for a range of waterbirds. The Inlet is fed by the Denmark, Hay and Sleeman rivers and several smaller waterways. It is bordered by low-lying swampy land, between coastal dunes and hills to the north and west, and the sand and limestone dunes of the Nullaki Peninsula to the south. Eucalypt forest and woodland, intersected by broad, swampy drainage lines, historically dominated the catchment. Today, much of the original vegetation has been cleared for agriculture.

Of the three main rivers, the Denmark River in the west remains in the best condition, with about 70 percent of the catchment still forested and much of the riparian zone in good condition. The catchment of the Hay River, which has the highest flow, is 70 percent cleared and contributes significant sediment and nutrient loads to the estuary. Smaller, heavily channelled waterways draining low-lying agricultural (e.g. potato growing) areas also contribute high nutrient loads. The increased nutrient levels have led to sporadic phytoplankton blooms, high levels of organic material and nutrient concentrations in sediments, and an increase in abundance of the seagrass *Ruppia megacarpa*. *Ruppia* is well adapted to cope with the variability in temperature, salinity and light availability that occurs on an annual cycle. It grows extensively throughout the estuary. On occasion, it can reach nuisance proportions, inhibiting boat movement and rotting offensively in large masses against the shoreline.

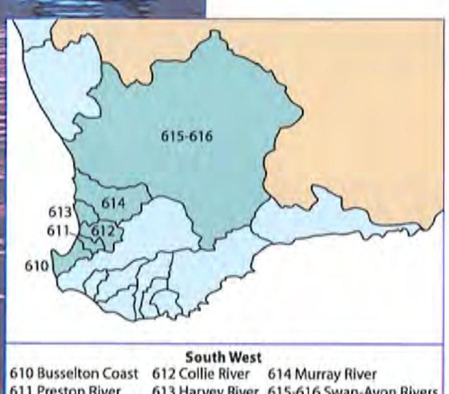
Wilson Inlet is closed for about seven months of the year, before the sandbar is opened manually around August to prevent flooding of agricultural land and residences. Bar opening can have only limited benefits for nutrient removal as most nutrients are delivered during winter run-off and are rapidly tied up in sediments and plant biomass. Given the high nutrient content of sediments, it is important to minimise stratification and low-oxygen conditions that promote nutrient release throughout the deeper mud-filled basins. It is clear that to successfully improve water quality in Wilson Inlet in the longer term requires a reduction in nutrient and sediment delivery from the catchment.

South West

Sandy coastal plains, drained rivers

The south west region of Western Australia includes the estuaries from the Swan–Canning south to Cape Leeuwin. The climate is Mediterranean, with most rain brought by cold fronts that move from west to east during winter, while the movement of deteriorating summer cyclones and thunderstorms from the northwest brings occasional unseasonal downpours. The highest rainfall is in the extreme southwest but it falls below evaporation levels to the north and inland. Catchment area in the coastal rainfall zone is the main control over river flows, however, very large catchments can still produce low flows because catchments are dry. Prevailing winds and swell are generally from the southwest, generating a northward littoral drift that creates sandbars across estuary mouths.

Most estuaries are permanently open and heavily impacted by catchment degradation. Tide range is small, 0.5 to 1 m at the coast and often 'damped' to less than 10 percent of this within estuaries; however, weather can cause fluctuations in water level that lead to inundation of shore areas. Many estuaries in this region lie behind dunes in the low coastal plain. Groundwater is important in this region as water is readily absorbed by the sandy soils of the coastal plain and retained within older, less permeable rocks and sediments. Though important in the past for wetland formation, much of the groundwater now flows directly into river systems due to draining and channelling.



The southwest of Western Australia is one of the world's biodiversity hotspots, with a diverse coastal heath and extensive forests in the wetter areas of the southwest corner. Estuarine flora is dominated by saltmarsh and brackish wetlands with salt-tolerant trees such as *Melaleuca cuticularis* and *Casuarina obesa*. Mangroves are confined to small stands of *Avicennia marina* in the Leschenault estuary. Estuarine seagrass communities provide important fish and invertebrate habitat and spawning areas as well as food for waterbirds such as swans. Only a handful of the nearshore seagrass species in the region are found within estuaries, with *Halophila ovalis* (Swan, Peel–Harvey) and *Ruppia megacarpa* (Peel–Harvey, Leschenault) the most common. Seaweeds (macroalgae) are a natural feature of these estuaries but have sometimes caused problems due to excessive growth resulting from increased nutrient loads.

Frequency and duration of bar opening are critical to fish spawning and survival and as a result, species numbers drop away rapidly as the frequency of opening decreases.

Crabbing in Peel Inlet

A favourite summer pastime in the Peel Inlet at Mandurah is crabbing. On a still afternoon dozens of people may be wading through the shallow estuary, armed with scoop net, size gauge and esky – and a pair of old sandshoes for protection from cobbler spines. They are stalking the elusive blue swimmer (manna) crab. Crabbing takes patience. The startled crab, roused from its rest in sand or weed, darts sideways with surprising agility. Swift reflexes and well-honed scoop skills are required to foil the escape. Once caught, the crab must be measured and checked for breeding condition, as undersized or spawning female crabs must be released (considerable fines apply). Blue swimmer crabs breed in estuaries and inshore waters around Australia. They normally grow to spawning (legal) size in their second year. Maintaining crab stocks is important for the many residents and visitors to Mandurah that engage in recreational crabbing. A growing population, and increasing demand for commercially caught crabs, is increasing pressure on crab populations. It is important not to take more than needed to help ensure crab numbers are sustained for the future.

Eutrophication, anoxia, viticulture, canal estates

Catchments along this region of the coast are intensively used by dairy, beef and piggery operations and horticulture industries, which release nutrients to the estuaries. Acid waters from bauxite, coal and sand mine de-watering are an issue in the catchment of the Leschenault estuary. The Swan coastal plain is extensively drained to prevent seasonal waterlogging and flooding from overcleared catchments. Thus, flows to estuaries have been highly modified. This, in combination with high nutrient loading land practices, low nutrient retention on the predominantly sandy soils, and poor tidal flushing of estuaries, has led to proliferation of macroalgae, blue-green algae blooms, lack of oxygen and fish kills. During the 1970s and 1980s, large quantities of stinking, rotting algae washed up on beaches in the Peel–Harvey estuary. Several species of green algae remain abundant in the eutrophic Swan and Peel–Harvey estuaries.

Impoundments on a number of rivers have reduced freshwater flows to estuaries. Salinity is increasing in flow from cleared, low-rainfall catchments. Rates of sediment deposition have greatly increased in many estuaries since settlement. The southwest has the fastest growing residential areas in Western Australia. Many of the developments are not compatible with the maintenance of estuarine values and residents adjacent to the estuaries often do not appreciate these values. Groundwater is tapped for urban water needs and is susceptible to contamination by nutrients and industrial wastes.

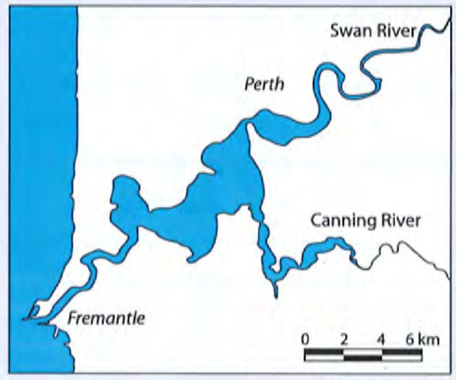
Major physical modifications have been made to some estuaries in the region, including engineering responses to combat symptoms of eutrophication. Algal blooms and fish deaths are common during summer and intensive agriculture and canal developments threaten the estuary. The very small Margaret River estuary has suffered reduced flows from water abstraction, principally for grape growing, which has also affected cave flora and fauna in the region.

Sunset over the sea, Watermans Beach, Perth

Swan–Canning Estuary

Stirling... named a port town, Fremantle, at the mouth of the Swan; and then led a party upstream, between embowered banks where the arch-symbols of antipodean inversion that had given the river its name, the black swans, dibbled their red bills in the water.

Robert Hughes, *The Fatal Shore*



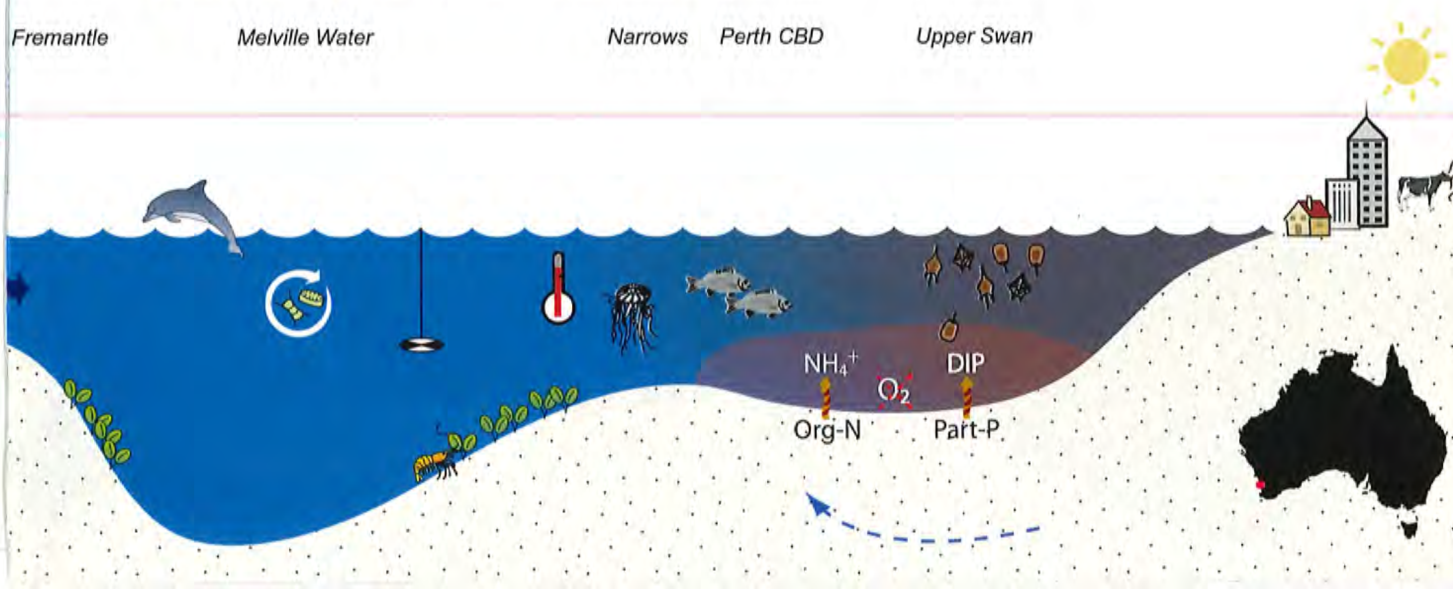
The Swan–Canning is a stratified or 'salt wedge' estuary, which separates into two major tributaries about 50 km from the mouth. The limestone bar at the mouth was removed in the 1890s for the port of Fremantle and the entrance channel, which was 2 m deep when first entered by European explorers, is now maintained at a depth of 13 m. This has greatly increased tidal exchange (from about 20% to 80% of ocean tides) and salty water now makes its way to the upper Swan, which becomes highly stratified during summer. Though highly valued for its recreational and aesthetic contributions to the city of Perth, the Swan–Canning estuary is a system under stress. Historically, water quality was worse than at present as pollution from industrial and urban point sources and from the expansion of fertilised agriculture in the catchment caused a proliferation of macroalgae. Reduction of point-source pollution and diversion of sewage discharges from the estuary has significantly improved water quality in the lower and middle estuary but algal blooms during the summer period remain a problem.

Agricultural and urban catchments still contribute a range of contaminants including nutrients. The Avon catchment is very large (the size of Tasmania) and contributes the bulk of freshwater flow. Flooding in this catchment can move large quantities of nutrient into the estuary with potentially dramatic effects as seen in the blue-green algae bloom of February 2000. Recent concern about the health of the Swan–Canning estuary has centred on the occurrence of relatively dense phytoplankton blooms, blooms of toxic species and anoxia in bottom waters. Phytoplankton blooms are common in the upper Swan and Canning rivers. During stratified periods when mixing of bottom and surface waters is limited, bacteria and other organisms use up oxygen in bottom waters to decay organic matter. This in turn promotes the release of nutrients stored in the sediments into the water column. These nutrients can then become available to promote the growth of various microscopic algae. Summer blooms are dominated by a few algae (especially dinoflagellates) that can

Water sampling at Marylands jetty, Swan Estuary (this page), Perth city (facing page)

- Groundwater movement
- Tidal exchange completely flushes the lower estuary with marine water and extends to the upper estuary
- Nutrient recycling
- Warm water
- O_2 Bottom waters of upper estuary are frequently hypoxic due to weak salinity stratification and low flow conditions
- DIP / Part-P: Anoxic sediments result in release of sediment-bound phosphorus (Part-P) to bioavailable dissolved inorganic phosphorus (DIP)
- NH_4^+ / Org-N: Anoxic sediments interrupt the nitrification process, therefore NH_4^+ builds up and diffuses into the water column
- High irradiance, long day length and high temperatures encourage phytoplankton blooms
- Water clarity is good in summer, up to 6 m in lower estuary and 1-2 m in upper estuary
- Dinoflagellates. Phytoplankton blooms, especially dinoflagellates are common in summer. Dinoflagellates are motile and can access nutrient enriched bottom waters
- Seagrass: *Halophila*
- Black bream move into the upper reaches in summer
- Dolphins frequently seen in the lower estuary. Sometimes in summer as far upstream as Perth CBD

The Swan-Canning Estuary in summer (illustration below)



migrate to the river bottom despite the stratified conditions then return to the surface to photosynthesise. Nitrogen and phosphorus both seem to play important roles in bloom initiation and duration. A reduction in the supply of these two nutrients is necessary to significantly reduce algal blooms. The Swan–Canning Cleanup Program aims to improve estuarine condition with respect to algal blooms.

The Swan River on a winter morning

Surface flows carry high concentrations of dissolved inorganic nitrogen (DIN) and particulate phosphorus (Part-P). They completely flush the upper Swan with fresh water and up to ~5 m in the lower estuary

DIN — A large amount of DIN from catchment inflows is exported out of the estuary to the Indian Ocean

Semi-diurnal tidal exchange volume is small compared with freshwater flow. The estuary is classified as microtidal

Part-P — Sedimentation of particulate-P from the catchment inflows

Groundwater from catchment rainfall recharges aquifers and discharges to the estuary above the saltwater interface. Some contaminated areas discharge DIP and NH_4^+ to the estuary

Most of the annual rains fall between June and August

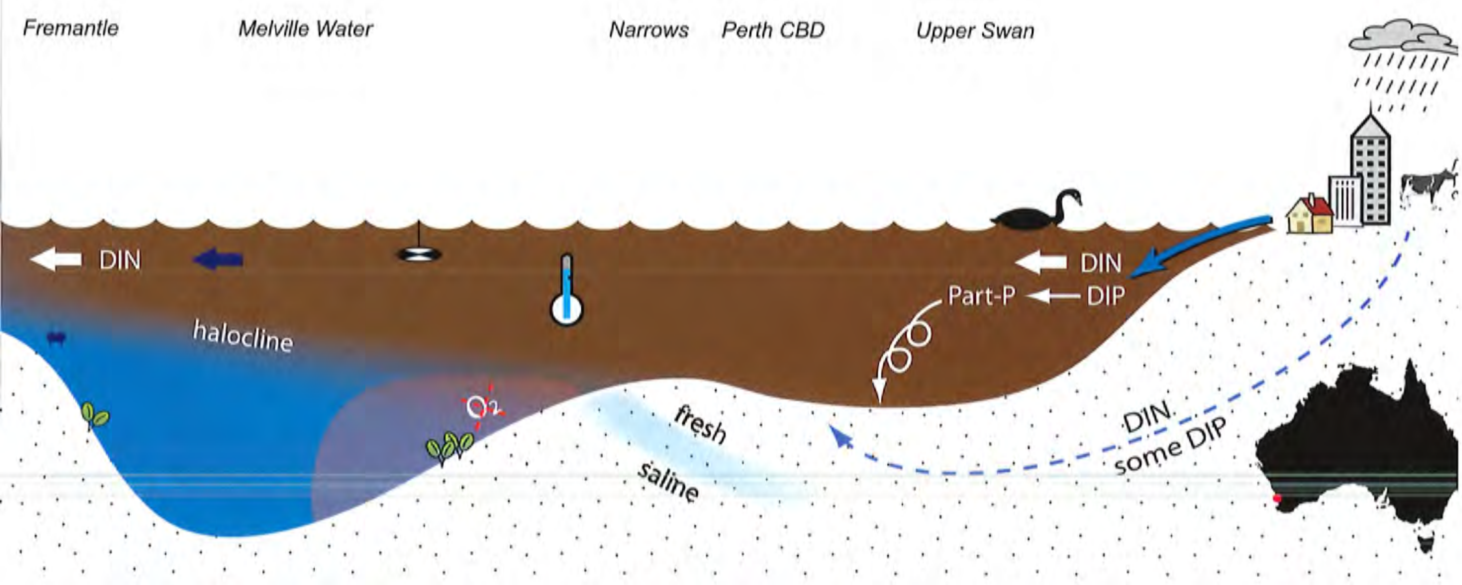
fresh / saline — Saltwater-freshwater interface in sediment

Poor light penetration due to tannin-rich catchment inflows, secchi depths generally < 1 m

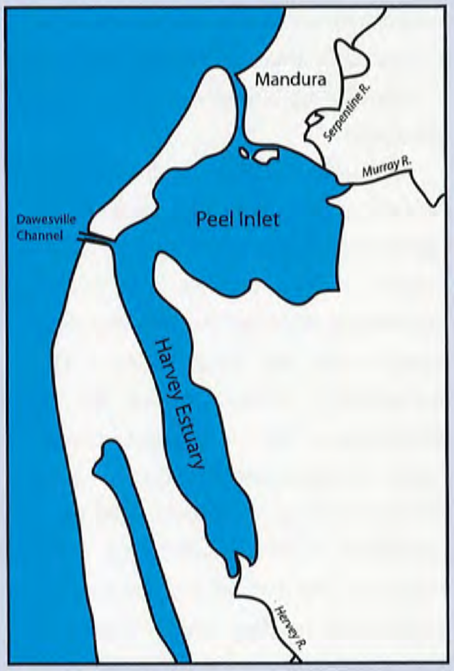
Negligible phytoplankton activity due to poor light penetration, flowing water and low temperatures

Cold water

The Swan-Canning Estuary during winter (below)



Case study: Peel–Harvey Estuary



The Peel-Harvey estuary is the largest estuary in southwest Australia (approximate area, 133 km²). It consists of Peel Inlet, a large, round, shallow basin, and the Harvey Estuary, an elongated lagoon between sand dunes. Both water bodies have their natural entrance through the dune system at the north of Peel Inlet (Mandurah), sheltered by a limestone headland. Under natural conditions, the long entrance channel and tidal deltas greatly restrict tidal flushing and the entrance is closed occasionally by shifting sands. Salinity varies seasonally from almost fresh in winter and spring to saltier than the local seawater in summer and autumn.

The Peel-Harvey estuary and its source rivers (the Serpentine, the Murray and the Harvey) have been extensively modified since European settlement. The upper reaches of the rivers flow from the ranges over the Darling Scarp to the coastal plain. Here, they historically formed meandering river systems, creating a series of interconnected wetlands. These drained slowly to the estuary across the coastal plain. As a result of major drainage works to prevent flooding, mainly after the 1930s, the Harvey and Serpentine rivers now flow through constructed channels for much of their length on the coastal plain.

In the early to mid twentieth-century, catchments were cleared, wetlands drained and channelled, and channels desnagged, causing freshwater flow to increase. This brought increases in sediment and nutrients in the estuary. The problem was compounded by rapid expansion of fertilised agriculture and the development of piggeries on sandy soils that retain little nutrient. The estuary was severely eutrophic by the 1970s. This led to profuse growth of macroalgae in Peel Inlet which washed up and rotted in massive

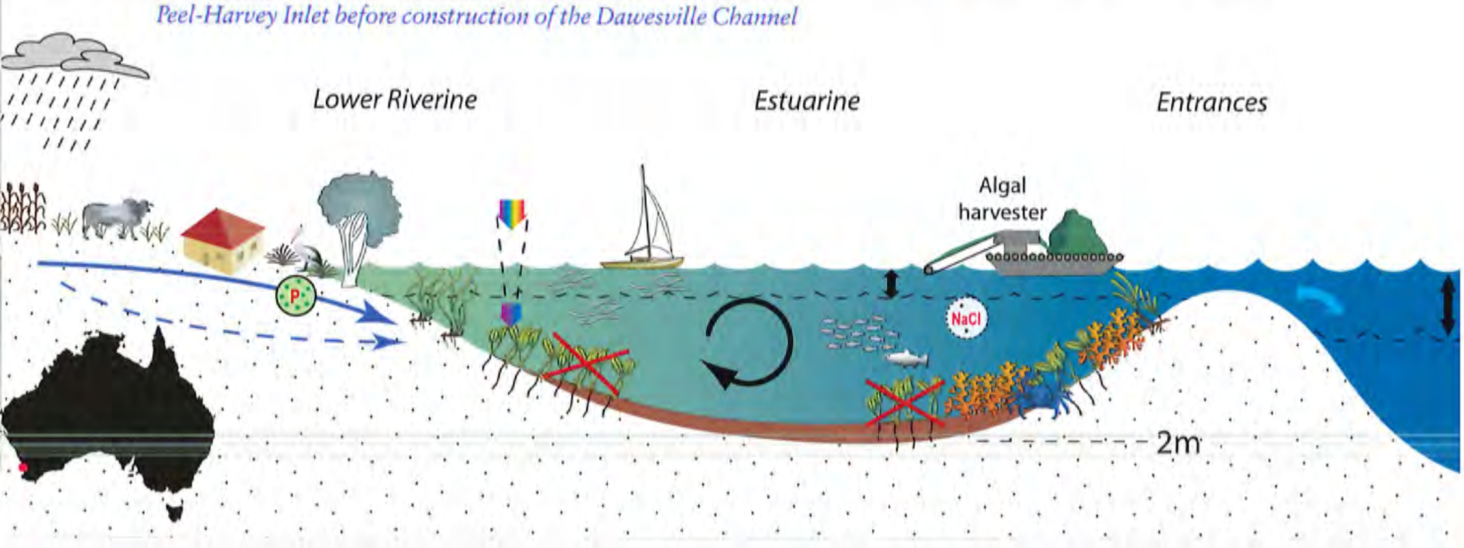
amounts on beaches. In the Harvey Estuary it resulted in seasonal blooms of the toxic nitrogen-fixing blue-green alga *Nodularia spumigena*.

Management approaches included harvesting seaweed, improving fertiliser application practices, applying bauxite residue or 'red mud' to farm soils and streamlining of drains that included riparian revegetation and stock control. These approaches either helped to bind phosphorus in the soil or reduced erosion. Finally, an engineering solution was deemed necessary to improve estuary water quality. The Dawesville Channel, completed in 1994 (2.5 km long, 200 m wide, 8 m deep at the ocean end and 4 m deep at the estuary end) was cut through the dunes at the northern end of Harvey Estuary. The channel was to flush nutrients from the estuarine basins and increase salinities to levels that inhibit growth of the toxic estuarine blue-green algae, *Nodularia*.

Construction of the Dawesville Channel has considerably improved water quality in the estuary, but blue-green algae *Nodularia* and *Anabaena*, and nuisance phytoplankton blooms, still occur regularly in the lower tidal reaches of the three inflowing rivers.

Aside from improving water quality in the estuarine basins and creating mixed water quality conditions in the lower tidally influenced rivers, a range of changes has occurred to the biota. For example, *Nodularia* has not bloomed since opening, and macroalgal growth is minimal, though profuse growth of a marine blue-green alga, *Lyngbya majuscula*, occurred between 2000 and 2002 near the Dawesville entrance. Water clarity has increased remarkably and substrates have become sandy. Fish, crabs and prawns now move in and out of the system more frequently, significantly altering the commercial and recreational fishery.

Peel-Harvey Inlet before construction of the Dawesville Channel



The benthic and zooplankton communities have more marine visitors and seasonal residents. Mosquito numbers have also increased, presumably due to the micro-flooding associated with increased tides caused by the Dawesville Channel. This data, however, is confounded by increased human population living in close proximity to the estuary. Shore erosion has increased, mainly in the Harvey and is believed to have led to death of shoreline vegetation and re-colonisation further back on the foreshore. Unfortunately, nutrients continue to flow in from the catchment unabated.

Dawesville Channel (above); Saltmarsh, Peel–Harvey Inlet (facing page)

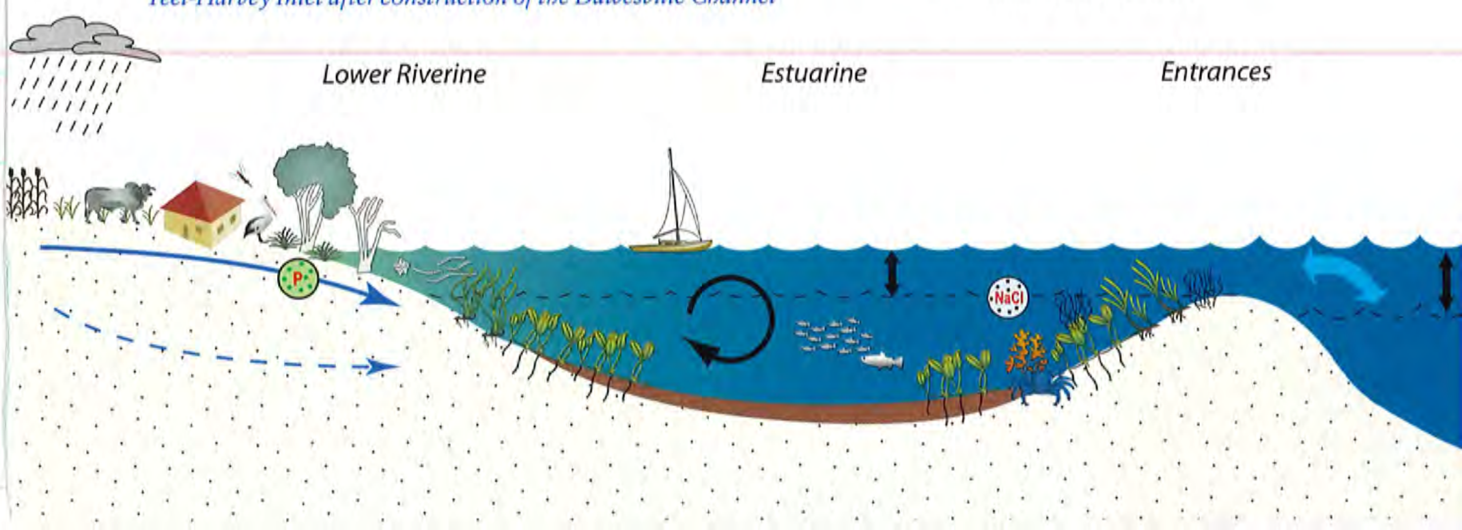
Before Dawesville Channel

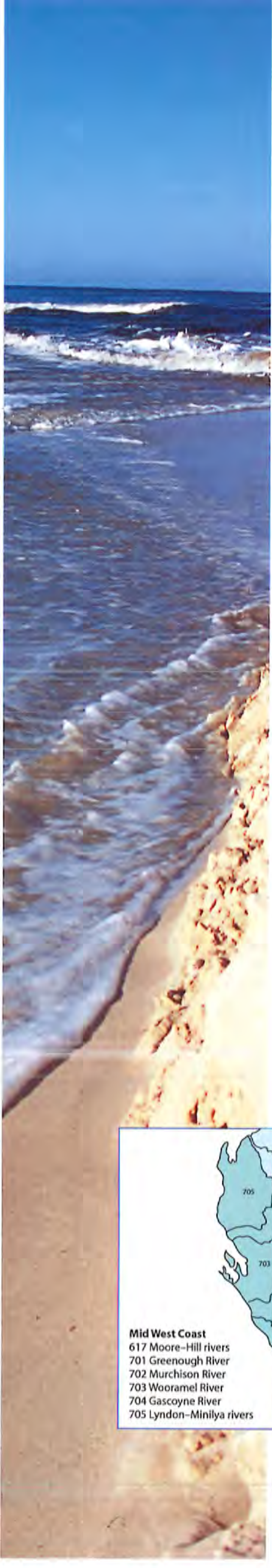
- The natural entrance has been modified by dredging and canals
- Prolific growth of macroalgae occurred in Peel Inlet due to nutrient levels
- Massive amounts of nuisance macroalgae were mechanically harvested
- Variable salinity, usually fresh to brackish in winter, hypersaline in summer
- Population centres at Mandurah and along the rivers
- Declining seagrass communities associated with eutrophication
- Toxic cyanobacteria (*Nodularia*) blooms most years from 1978 in the Harvey estuary
- High concentrations of phytoplankton reduced light penetration in Harvey estuary
- Tidal range of the estuary was only ~12-14% of the ocean tide

After Dawesville Channel

- Construction of a second entrance has increased oceanic exchange (3 to 5 fold)
- Macroalgae populations declined dramatically
- Salinity in the estuary has increased (Bottom salinities rarely go below 20 ppt.)
- Increasing population includes marinas & canal estates at Dawesville entrance & old entrance channel
- Cyanobacterium Lyngbya majuscula grew prolifically in Peel Inlet 2000–2002 but has declined again
- Cyanobacteria and dinoflagellate blooms occur periodically in the lower riverine areas
- Halophila, a prostrate seagrass, has increased throughout Peel Inlet and the northern Harvey
- An increase in tidal range to ~50% of ocean tide has increased the intertidal area especially in the Harvey estuary
- Tree deaths and shore erosion have increased especially in the western Harvey
- Increase in diversity and abundance of fish with marine affinities
- Increase in mosquitoes associated with microflooding of fringing saltmarshes

Peel-Harvey Inlet after construction of the Dawesville Channel





Mid West Coast

This part of [New Holland] is all low even land with sandy banks against the sea... The land is of a dry sandy Soil, destitute of Water, except you make wells, yet producing divers sorts of Trees; but the Woods are not thick, nor the trees very big...

William Dampier

Rangelands meet the sea

The Mid West Coast region, from Giralia Bay south to the Moore River, is arid to semi-arid with occasional cyclonic influences. Rainfall averages about 200 mm a year in the Gascoyne region from Shark Bay north, but increases to the south, averaging about 460 mm around Geraldton. The major river systems in the region are the Murchison and Gascoyne, which for the most part are just strings of waterholes. Freshwater flows tend to be ephemeral, though occasional floods are associated with summer storms and rain depressions brought by deteriorating cyclones from the north. This coast is dominated by the belt of southeast trade winds, which generate southerly winds for most of the year.

Estuarine water levels in the summer are sustained by groundwater. In the lower reaches of estuaries, this groundwater flow is high in nutrients. Nutrient levels are lower in the upper parts of the estuaries. In this area, marine and terrestrial species from the tropical zone mix with temperate species. Current understanding of the ecological communities in these estuaries is poor.

Ecotourism: feeding the dolphins

While early European explorers left with a somewhat jaundiced assessment of Shark Bay due to the low, arid landscape and lack of available freshwater, it is now recognised worldwide as a natural marvel for its profusion of aquatic life. The dome-shaped stromatolites at Hamelin Pool are created by cyanobacteria, organisms that have changed little in the past 3.5 billion years. Turtles and dugongs abound in the seagrass beds and can be seen from the shore at Eagle Bluff on the west coast of Peron Peninsula. A number of shallow diving and snorkelling sites are also dotted around the bay, but the biggest attraction for many visitors is the feeding of the bottle-nosed dolphins at Monkey Mia. Their habit of coming right into the beach dates back to the 1960s (when fishermen began feeding the dolphins as they returned with their catch) and has been passed on through three generations of dolphins. Small groups (about 7 or 8 of the 100 or so dolphins recognised in the bay) now visit the beach most mornings and accept fish from visitors who can interact with them in the shallows. The feeding of the dolphins is strictly controlled to ensure they do not become dependent on human handouts.

Fragile ecosystems

Pastoralism, some horticultural production, mining (including salt mining), fishing and tourism dominate land use in the northern Gascoyne region from Exmouth Gulf to Shark Bay. The extreme environment in this region supports fragile ecosystems that are highly susceptible to human disturbance. Catchments are likely to come under increasing pressure if predicted growth in horticulture eventuates. Irrigated production of tropical crops currently occurs at Carnarvon, at the mouth of the Gascoyne River. This river, which discharges into the Indian Ocean just north of Shark Bay, has a heavily grazed catchment. As a result, it transports massive amounts of sediment into the Indian Ocean and Shark Bay during rare flood events. South of Shark Bay, the Murchison River drains an extensive agricultural and pastoral catchment. In its lower reaches the river passes through Kalbarri National Park. Estuarine sediments in the Murchison have elevated levels of lead, a legacy of mining from the 19^{th} century.

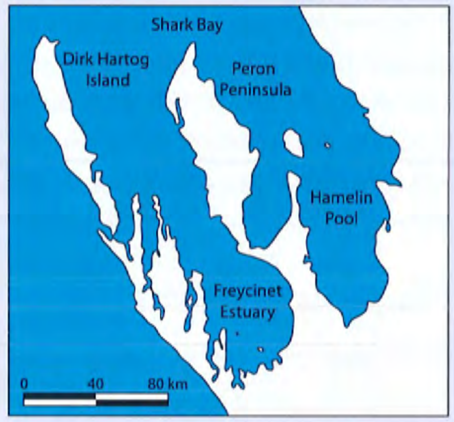
North, and particularly south of Geraldton, the northern wheat belt extends right to the coast, so many of the estuaries in this area are heavily impacted by agriculture. Sedimentation and algal blooms are concerns. The estuaries here are important for recreational fishing but are not fished commercially due to eutrophication and habitat loss. The catchment of the Moore River is extensively cleared, highly saline and flood affected, though the riparian vegetation around the estuarine portion is in reasonable condition. Fishing and canoeing are popular activities on the estuary. The bar separating the estuary from the ocean breaks periodically over winter and spring due to rising water levels triggered by winter rains. The Save the Moore River Campaign demonstrates community interest in the estuary's health.

Fishing the Moore River bar – open (below); barred entrance to Moore River showing dark, tannin-stained water (bottom); Limestone cliffs near the entrance to Moore River (facing)

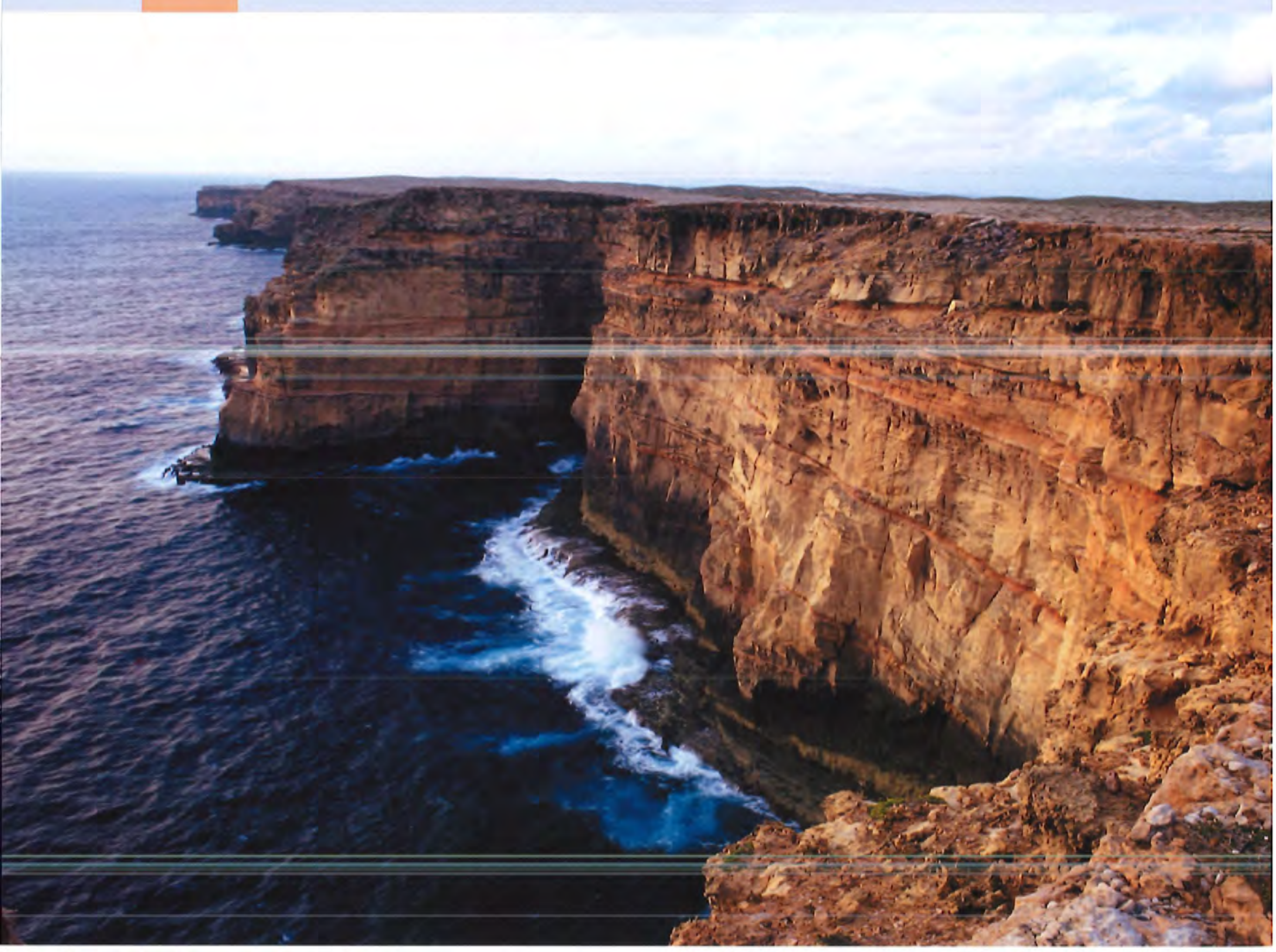
Case study: Shark Bay

The Sea-fish that we saw here (for here was no River, Land or Pond of fresh Water to be seen) are chiefly Sharks. There are Abundance of them in this particular Sound, and I therefore give it the Name of Shark's Bay.

William Dampier



Although technically not an estuary due to the negligible freshwater flow it receives from the catchment, Shark Bay (13,000 km^2) deserves special mention as a unique 'inverse' estuarine environment. The bay is shallow, being less than 15 m deep over most of its area. Evaporation in this hot, dry region causes salinity to increase to levels well above seawater. In the western Freycinet estuary, salinity reaches 45–50 parts per thousand, while in Hamelin Pool, in the eastern bay, it often exceeds 60 parts per thousand (seawater has a salinity of about 35 parts per thousand). Shark Bay is a declared World Heritage Area (one of the few listed for having all four outstanding natural universal values) and a Marine Park. It is recognised for its world-renowned stromatolite deposits as well as some 103,000 ha of seagrasses, one of the largest and most diverse seagrass beds in the world.

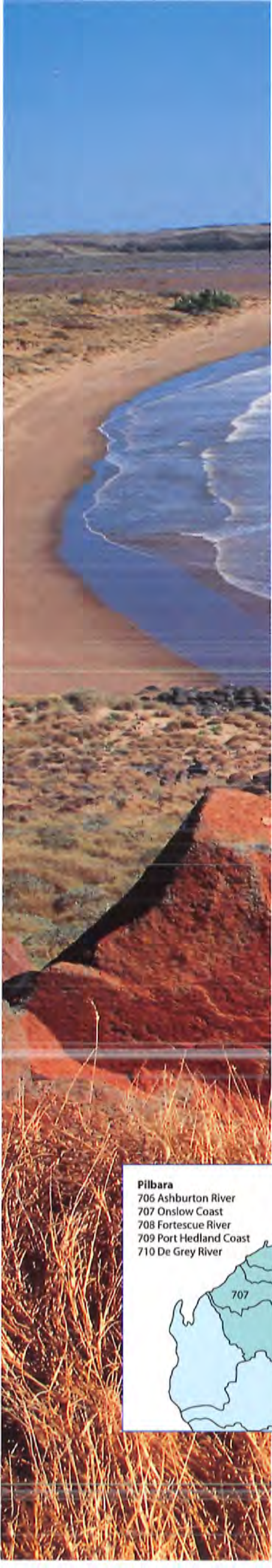


Twelve species of seagrass grow in the bay, which represents an overlap zone for tropical and temperate species. The dominant species, which covers about 85 percent of the seagrass area, is *Amphibolis antarctica*. The seagrass beds are a major nursery area for marine fishes and prawns, as well as supporting a large population of dugongs. *Avicennia marina* is the only mangrove species present.

Shark Bay wildflowers

The area has high aesthetic value for tourism due to its physical setting and the opportunities to observe large marine animals and waterbirds. Dolphins are an international tourist attraction at Monkey Mia. Shark Bay is a popular site for recreational fishing and boating and some disturbance to seagrass beds has resulted from excessive boat traffic in shallow areas. A salt lease covers part of the area and the park is fished both recreationally and commercially. Commercial fishing includes prawns, scallops, snapper and sand whiting. Some pearl oyster production occurs in the bay. There is some grazing, especially of sheep, in the surrounding area.

Charismatic megafauna at Shark Bay – Dugong family life (right); dolphin and human family life (below)



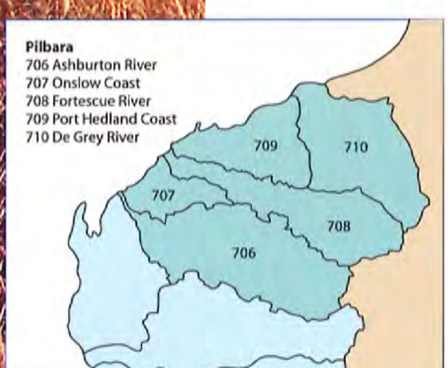
Pilbara

Arid land, big tides, inland river deltas

The Pilbara is a region of arid coast line with rivers that rarely run to the sea and which, during the infrequent wet seasons, empty directly to the coast. Drought periods may extend for several years, with scattered summer thunderstorms and occasional tropical cyclones providing almost all the rainfall. As a result, river flows are ephemeral with occasional large floods. For the majority of the time, seawater penetrates river mouths. At times there is considerable sedimentation, in places creating 'inland deltas'. Evaporation rates in the Pilbara are extremely high. The region includes some of Australia's consistently hottest places. Tide range along the Pilbara coast is large, about 4 m. Catchments are generally hilly, and several undulating iron-rich ranges are present further inland.

Pilbara mangroves are less diverse than those further north or at a similar latitude on the east coast

The extreme heat and aridity, and the resulting ephemeral freshwater flows in this region, restrict the establishment of estuarine vegetation. Such vegetation may suffer extensive droughts and hypersaline soil conditions during arid periods. On the other hand, it is exposed to high volumes of freshwater run-off during cyclones. Mangrove communities are less well developed than those further north or at similar latitudes in eastern Australia. The coast from Northwest Cape to Dampier has less diverse mangrove communities than that from Dampier to Port Hedland. The Eighty Mile Beach north of Port Hedland has no mangrove development. Tidal flats in the region grade into areas of saltmarsh and saltpan. Saltmarsh vegetation is extremely sparse, with succulents and grasses being the main species.



Diving Ningaloo Reef

From mid-March to mid-May each year divers from around the world make the pilgrimage to Ningaloo Reef for the unique experience of diving with the majestic whale shark. Nowhere else in the world can these giant fish (whale sharks reach more than 12 m) be seen in large numbers at predictable times of the year. Ningaloo Reef is a 260-kilometre-long fringing reef surrounding the Ningaloo Peninsula that forms the western boundary of Exmouth Gulf. Ningaloo Reef is entirely protected within the Ningaloo Marine Park. It is the largest fringing coral reef in Australia and the only large reef in the world found so close to a continental landmass. Divers and snorkellers can see whales, dolphins, dugong, manta rays, huge cod or sharks, as well as over 180 species of coral and hundreds of species of colourful tropical fish. Mass coral spawning can be seen from Exmouth or Coral Bay a week or so after the full moon during March and April.

Port development on tidal flats

Catchments in the Pilbara are extensively grazed by sheep and cattle. Mining, particularly of iron ore, is a significant industry. Several large mining settlements including Tom Price and Newman are located in the ranges. From this area iron ore is transported by train to the coast. Port Hedland and Dampier/Cape Lambert are export ports for the mining and oil industries and for salt. These ports receive more ballast water than any other port in Australia, with associated high risk of pest invasion. Port Hedland is the busiest port by tonnage in Australia and the Port Hedland saltworks exports about two million tonnes per year. Handling of massive amounts of iron ore produces clouds of dust that have affected the health of mangroves in the harbour. Karratha is a base for the offshore oil industry. Most of the estuaries in the Pilbara region are in a largely unmodified condition but they are recognised as being highly vulnerable ecosystems due to the high degree of natural stress on estuarine and catchment wildlife in this hot, dry environment.

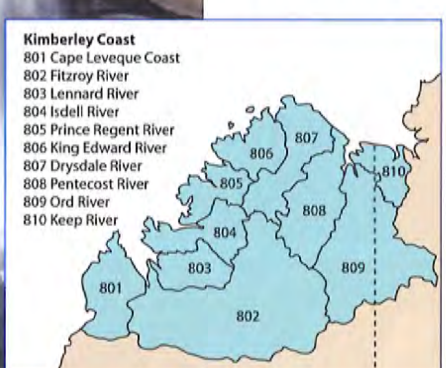
Causeway, Dampier (below); diving on Ningaloo Reef (bottom)

Kimberley

Enormous tides and monsoonal rain

The Kimberley region in the north of Western Australia extends from the Northern Territory border to the Dampier Archipelago. The coastline is a jagged series of inlets, bays, islands and reefs. Rivers flow through rocky catchments, many through a plateau landscape of generally low relief with waterfalls flowing over steep escarpments. Estuaries here have huge tide ranges – up to 12 m. The climate is tropical with extreme wet/dry seasonality and great variability from one year to the next. River flows are small to negligible during the winter drought, while summers can bring extended hot and dry periods or flooding monsoonal rains and tropical storms. Several river systems contribute significant river flows during wet seasons, the largest of these being the Ord and the Fitzroy rivers. The Fitzroy, which has the highest annual discharge of all rivers in Western Australia, rises in the central Kimberley Plateau and runs through several spectacular gorges before meandering across an extensive floodplain to the estuary mouth in King Sound.

Monsoon rainfall and the high tide ranges provide suitable conditions for fringing mangroves and saltmarshs, though extreme heat and evaporation during the long dry season stunt growth in estuarine vegetation. Several estuaries have vast mangrove forests with well-developed zones, as well as large areas of saltmarsh and saltpans. The Kimberley region contains most of the significant mangrove areas in Western Australia (e.g. the Cambridge Gulf has 14 species). Seasonal wetlands on river floodplains are an important feature of the larger rivers. Kimberley estuaries are important breeding and habitat areas for saltwater crocodiles. A number of areas provide important permanent and seasonal habitat for waterbirds. Little is known about the natural processes driving these estuaries.



Safari fishing

The Kimberley has a reputation for providing virtually untouched fishing grounds, which contributes in no small part to its mystique among recreational fishers. The isolation and rugged physical beauty of the Kimberley create the perfect backdrop for some of the best fishing in the country. A wide range of estuarine, reef and pelagic species can be caught, but the fish most prized by anglers is the barramundi. Fishing in the Kimberley is based around the seasons and immense tides, the best time being March to November. Of the estimated tens of thousands of people fishing in the region each year, the vast majority do not venture far from the population centres of Broome, Derby and Wyndham. Most of the Kimberley coast is inaccessible by road and the many mangrove creeks and estuaries, offshore reefs and islands in these areas are the preserve of those who can afford to take a charter on a long-distance boat or fly in by helicopter.

Dams, mines and tourism

Although most of the smaller tidal creeks and estuaries remain near-pristine, the larger river systems in the Kimberley have all been affected by catchment land use to some extent and pressures on these estuaries are likely to increase. Though currently remote and sparsely settled, the Kimberley is becoming a focus for regional development plans in Western Australia. The regional population of approximately 28,000 represents a 40 per-cent increase over the past decade. This is swelled further by an influx of tourists from May to October. Almost half of the resident population is Aboriginal. Indigenous land and water rights are an important issue for managers in the region. The Kimberley economy is centred on tourism, agriculture, mining, pearling and fishing. Aquaculture is an emerging industry with several aquaculture projects currently proposed or being developed. The development of irrigated agriculture and horticulture has mostly centred on the impoundments on the Ord River (see case study) but has also occurred in areas north-east of Broome and near Derby, and may extend in the near future.

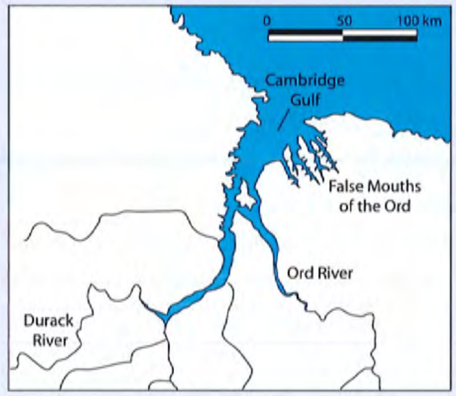
Rangelands production of beef dominates the pastoral industry and is associated with riparian habitat destruction and increased sediment and nutrient loads in run-off. Mining on the plateau is a significant industry which may carrying mine tailings and other by-products of ore processing to estuaries via run-off. A new lead and zinc mine and milling complex has been built at Pillara. The Argyle Diamond Mine, the largest in the world, is situated near Lake Argyle. An ore loading facility is planned for Londonderry Creek. More direct impacts to estuaries may result from future mining of alluvial diamonds.

Little effort has been made to assess the potential impacts to estuaries of commercial and recreational fishing in the region, which predominantly target barramundi. Though impacts of tourism have not been assessed, some bush camps and fishing charter activity have been associated with problems such as litter. Tourism is an important, growing industry, focussed on the unique natural features of the region. It provides an important opportunity for conservation of the ecological and aesthetic values of the region as a foundation for the regional economy.

Inland from Koolan Island, Kimberley region (facing page)

Tidal flats, King Sound (below)

Case study: The Ord River



The epitome of agricultural development in northwest Australia is the Ord River Irrigation Scheme. In an area of moderate but irregular rainfall (mean annual rainfall at Wyndham 717 mm) agricultural development has totally depended on the construction of large-scale dams for the production of crops such as sugar, cotton and various higher-value niche crops. The Ord River has been heavily regulated through the construction of two large dams to form Lake Kununurra (completed 1963) and the larger Lake Argyle about 50 km upstream (completed 1972). Demand for water has increased greatly in recent years with the ongoing expansion of the Ord Irrigation Scheme (Ord Stage 2) following recent success with sugar and the construction of a sugar mill in 1996. Cotton growing impacts are currently being assessed. Stage 2 of the Ord Scheme, a joint project of the Western Australian and Northern Territory Governments, is to increase the current 14,000 ha of irrigated land by as much as 64,000 ha.

The Ord River discharges into Cambridge Gulf north of Wyndham, where it forms the east arm of that estuarine system. Unlike the west arm, which is the estuary of the Durack and Pentecost Rivers, the Ord River estuary is silting measurably as a result of reduced wet season flows that previously flushed sediment supplied by tidal energy from Cambridge Gulf. Under natural conditions the Ord River estuary was dependent on periodic flushing by floods associated with monsoonal rains in the catchment. Reduced wet season flows have led to infilling of the estuary by marine sediments and increased penetration of marine waters throughout the year. Cattle access is also responsible for significant bank erosion in some areas of the catchment. The estuary systems of Cambridge Gulf have been jointly listed as wetlands of international importance under the Ramsar convention (as have Lakes Argyle and Kununurra) and a proposal has been made to form a Cambridge Gulf Marine Park incorporating Ord estuary and False Mouths of the Ord.

The Ord River

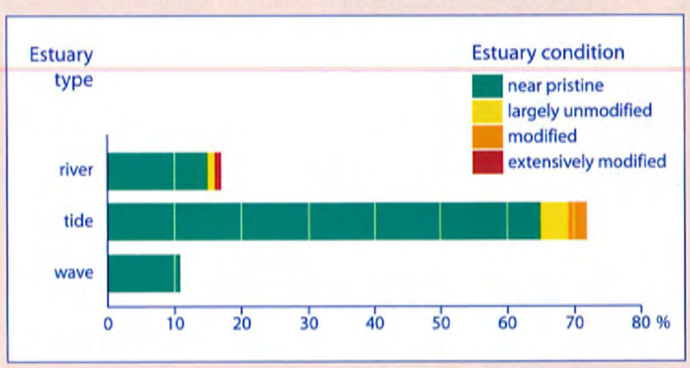
Estuary management in Western Australia	
Management arrangements	Responsibility for the management of estuaries is currently in a state of flux due to Government Department amalgamations. The Water and Rivers Commission collects, manages and uses data from estuaries and rivers, and fisheries data resides with Fisheries WA. The level of estuary management in much of the north of the state could best be described as 'benign neglect'.
Key issues	• Achieving a well-informed, involved and active community • Population growth and expanding coastal development in the southwest • Combating eutrophication, sedimentation and increasing salinity in coastal lagoons • Emerging development pressures in the north of the state • Prevention of further development in near-pristine environments with development activities to focus on already modified estuaries • We are presently loving our estuaries to death. We need better ways of managing human interactions with estuarine environments. • Achieving better integration of estuarine management issues with coastal planning
Key management responsibility	• The **Department of Environment (DoE)** has been formed by amalgamating the **Department of Environmental Protection (DEP)** with the **Water and Rivers Commission (WRC).** The **Swan River Trust** is responsible for managing the waterways and shorelines of the Swan–Canning river system. • **Department of Fisheries** – management of estuarine fisheries
Policy and legislation	Management of estuaries is not specifically covered by legislation, although the *Waterways Conservation Act 1992* and the *Environmental Protection Act 1986* provide the broad legislative framework. The approach of the current Water and Rivers Commission is to include estuaries in the context of a whole-of-catchment management approach consistent with current national thinking about natural resource management (NRM). In areas of concern, the former Waterways Management Authorities have been superseded by advisory committess which are now integrated into the broader NRM-based regional strategies. The community-based Geocatch Network for the Vasse Wonnerup is a more extensive approach which links catchment, estuary and marine issues. Environmental Protection Policies or EPPs are a policy instrument applied to estuaries such as the Peel–Harvey and more recently the Swan–Canning. The Cockburn Sound EPP will soon be applied to this complex multiple-use area, the management of which is coordinated by the new Cockburn Sound Management Council representing community, government and industry.
Community initiatives	• The leading community-based monitoring organisation in Western Australia is **Ribbons of Blue,** formed as part of the Australia-wide **Waterwatch** network. Ribbons of Blue is coordinated by the Water and Rivers Commission. • The **South Coast Regional Initiative Project Team (SCRIPT)** groups catchment communities and agencies concerned principally about agricultural catchments but also includes estuaries. • A range of community groups are involved in estuary and catchment management, and the number of groups is increasing (by mid–1998, 13 Integrated Catchment Management groups were established in the Swan–Canning catchment alone). The challenge is to integrate and channel the energy of these organisations to best achieve beneficial outcomes for the estuarine environment. • Community awareness and concern about estuarine issues varies considerably along the coast, and not all catchments have active community groups.

chapter 11

Estuaries of the Northern Territory

The Northern Territory is remote and its population sparse. As a result, most of its estuaries remain near-pristine in condition. They are excellent habitat for some of the densest populations of estuarine crocodiles in the world. As well as the sea- and water-birds that roost here many other marine animals and plants live in the area. By studying these pristine estuaries we can better understand what is happening in modified estuaries in other parts of the country. The management focus of the Northern Territory estuaries is to keep them in good condition rather than having to repair the results of past bad management. The estuaries in the Gulf of Carpentaria also support prawn and finfish production in the gulf.

Estuaries of the Northern Terrirtory – type and condition

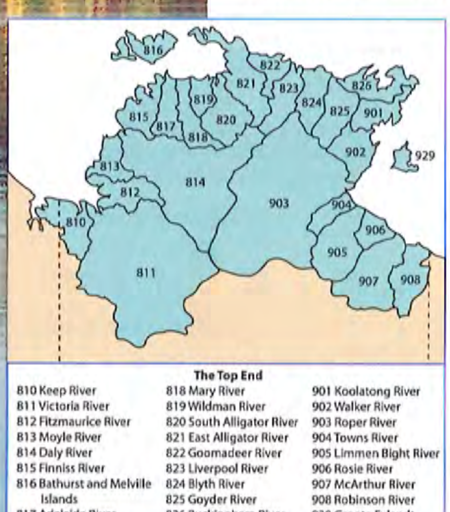


The Top End

The Big Wet

Northern Territory estuaries are all in the wet/dry tropics of northern Australia. Practically all rain falls between November and April. Aboriginal groups recognise different seasons for example, the Bininj/Mungguy people in the Kakadu region have six: *gunumeleng* (pre-monsoon storm season), *gudjewg* (monsoon season), *banggerreng* (knock 'em down storm season), *yegge* (cooler but still humid season), *wurrgeng* (cold season), *gurrung* (hot dry weather).

Rainfall is about 1500 mm in the Darwin area. Tropical cyclones are less frequent than on the northeast and northwest coasts of Australia. Coastal catchments flow to the Gulf of Carpentaria in the east, the Arafura Sea to the north and the Timor Sea to the west. In the north, a monsoonal wet season causes high rainfall, whereas in the eastern and western regions a combination of weaker monsoons and cyclones makes rainfall highly variable from year to year. River flows into estuaries are correspondingly highly variable. Depending on the extent of monsoon fronts and cyclonic activity, the size of annual floods varies between years. During the dry season, the majority of rivers stop flowing into the sea. An important influence on Northern Territory estuaries is the huge tides along the northern and western coastlines.



There are no major river systems on the western shore of the Gulf of Carpentaria, other than the Roper River, which flows into the southwest corner of the gulf. The major drainage of Arnhem Land is in the south to north direction.

The major river systems of the Northern Territory have vast freshwater and tidal wetlands and floodplains. Mangroves are extensive and diverse. Meandering estuary channels often have fringing mangrove forests, beyond which are grassplains, saltpans or claypans with cracking soil, largely devoid of trees and shrubs. Mudflats and samphire are common in lower estuarine areas. Swamps and seasonal lagoons on the coastal floodplains are breeding areas, habitat and refuge for an extraordinary abundance of birds during the wet season. Northern Territory estuaries are also important habitat and breeding areas for estuarine crocodiles and fish such as barramundi.

Catching fish in Arnhem Land

Traditional fishing methods are still used by the eastern Gunwinggu people of northern central Arnhem Land. During the early dry season (*yekeh*), a time of plentiful food, fish traps are used to catch barramundi and catfish. The traps, called *manjabu*, are about 1.5 m long and are made from lengths of vine (*milil*) attached to a wooden frame (*gudjirrino*). A removable conical attachment at the front (*manyaw*) allows fish to enter but not to escape. The traps are used on the ebb tide and are placed in a gap in a permanent fence across the stream. As the tide recedes, the fish travel downstream and are funnelled along the fence and into the trap. According to custom, making and using *manjabu* is restricted to older men. Women and children are not allowed near the fishing site. People are not allowed to sleep near the site and conversations are kept to whispers. Traditional fishing methods are being replaced by lines and lures, which are predominantly used by young people. Other techniques used by Indigenous people in northern Australia include stone traps on beaches, fishing lines with shell or bone hooks, spearing and, in the Torres Strait, specially constructed scoops.

Development at any cost

The vast majority of estuaries in the Northern Territory are in a near-pristine state due to minimal catchment and shoreline development and low population density. With the exception of the Darwin region and Nhulunbuy in the northeast, the Northern Territory coastline is sparsely populated. Much of the coast is remote and inaccessible by land. These areas are populated by Aboriginal communities and pastoral property homesteads. Approximately half the Northern Territory coastline is Aboriginal land, with the remainder being either freehold or pastoral lease. The dominant and often only land use in the catchments is grazing.

Northern Territory estuaries have been principally modified by developments along the shoreline (e.g. port facilities) and in the immediate catchment (e.g. urbanisation). There are fewer than 10 point-source discharges to estuaries along the Northern Territory coastline. These are mainly in Darwin Harbour. The extent of modification to estuarine ecological integrity, however, has not been well documented or quantified. Two estuaries have been severely modified, though it is uncertain whether this has been caused by human activities. Two tidal creeks draining the Mary River freshwater wetlands have moved over 30 km landward, flooding once freshwater areas with salt water. Through the construction of barrages this has been controlled but needs ongoing work. Some parts of the Mary River coastal wetlands are returning to a freshwater state. There is evidence of other coastal areas affected by the landward expansion of tidal creeks with saltwater intrusion into freshwater areas, though not to the same extent as in the Mary.

Rock art illustrates the long association of Indigenous people with estuarine fisheries (above);

Jabiru on the floodplain, Kakadu National Park (facing)

Case study: Darwin Harbour

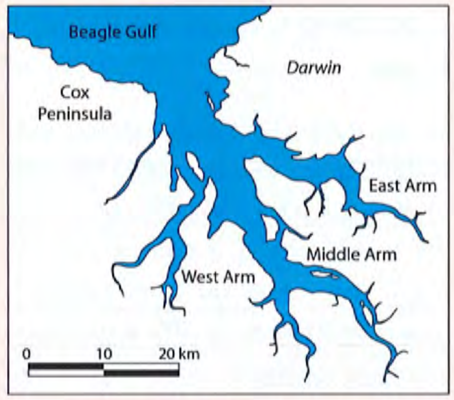
Darwin was founded in 1869. Since that time the city has had major damage inflicted on it by Japanese bombings during the second world war and by cyclones. After Cyclone Tracy, the most serious cyclone to hit Darwin, resulting in 50 deaths on Christmas day 1974, there were proposals to move the city inland to safety from these devastating storms. However, Darwinians would not give up their harbour, bays, headlands and beaches.

Creek mouths and bays within Darwin Harbour offer good fishing but caution is needed when fishing from banks as saltwater crocodiles are a constant threat.

The exotic pest, the black-striped mussel (*Mytilopsis* sp.), was first found in Darwin Harbour in 1999. A marine pest survey of the harbour in late 1998 found no trace of the mussel but by March 1999 divers from CSIRO's Centre for Research on Introduced Marine Pests found them in large numbers, covering almost every marine structure in Cullen Bay Marina.

The black-striped mussel is a native of Central and South America. It lives in the tropical and subtropical waters of the western Atlantic Ocean from the Gulf of Mexico to Columbia and is one of the world's most damaging marine pests. It is presently found throughout the Indo-Asia region from India to Japan but this was its first incursion into Australian waters. Apparently the mussel was introduced into the Cullen Bay Marina in October 1998 attached to the hull of a boat. It may have been transported as larvae in ballast water but this is unlikely due to its short larval period. The mussel was then spread to Tippery Bay Marina. Vessels which had been moored in Cullen Bay Marina and now infected with the mussel were found in Frances Bay Marina, Sadgroves Creek and Spot On Marine, though no mussels were found on other structures at these sites.

The black striped mussel grows quickly, usually becoming reproductive within two or three months. A single female can spawn 50,000 eggs every 28 days. Productivity of the mussel can be as high as 100 kg/m^2 per year. It lives for 20 months and reaches maximum length of approximately 2.5 cm within six months.



Beware of lurking crocs if fishing in creeks and bays around Darwin Harbour

Double gates on marinas allowed the spread of the black-striped mussel to be prevented

Its high fecundity and growth rate combined with its ability to survive a wide range of salinities, temperatures and other marine conditions, give the black-striped mussel the potential to infest much of the Australian coast from Fremantle (WA) to Sydney (NSW). As the mussel can out-compete other sessile invertebrates and grow over them, it has the potential to impact heavily on native species and on the economically important aquaculture and fisheries industries. Through the fouling of anchors, ropes, pylons, buoys, boat hulls and intake/outlet pipes the mussel is capable of causing millions of dollars damage to maritime industries a year.

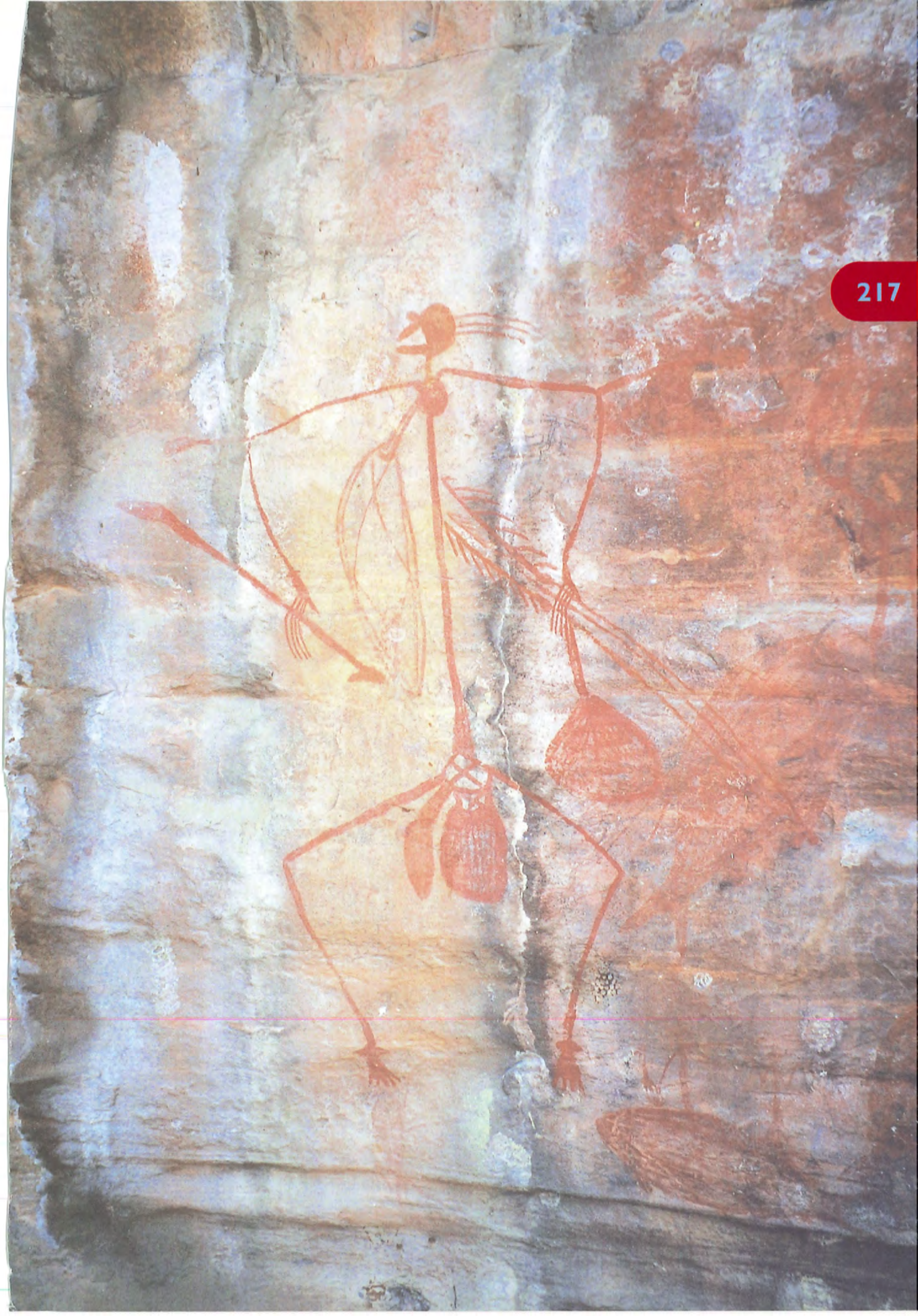
Luckily for the people of Darwin, and Australia, a successful eradication program was launched. The marinas where the mussels were found are now enclosed with double gates across the entrances to control water levels during the high tidal range within Darwin Harbour. The gates were closed and the water was treated with copper sulfate and chlorine to kill the mussels. To date, there have been no further outbreaks of the mussel in Darwin Harbour. The eradication of the black-striped mussels from Darwin Harbour is the world's first known case of the successful removal of an established marine pest. This cost in excess of $2.2 million.

As a result of the introduction of this pest, all internationally travelled vessels that have not been anti-fouled within Australian waters must now undergo a hull inspection and treatment of their seawater systems before entering Darwin marinas. The waters of the harbour are now monitored via photography at fixed sites and settlement collectors are used in marinas and high traffic sites. These detachable plates and ropes (settlement collectors) are regularly checked for pest species. Thus researchers are able to monitor the recovery of marinas which had been chemically treated.

The community and government of the Northern Territory are dedicated to keeping out marine pests in order to protect the North's way of life and the rich marine biodiversity of Darwin waters.

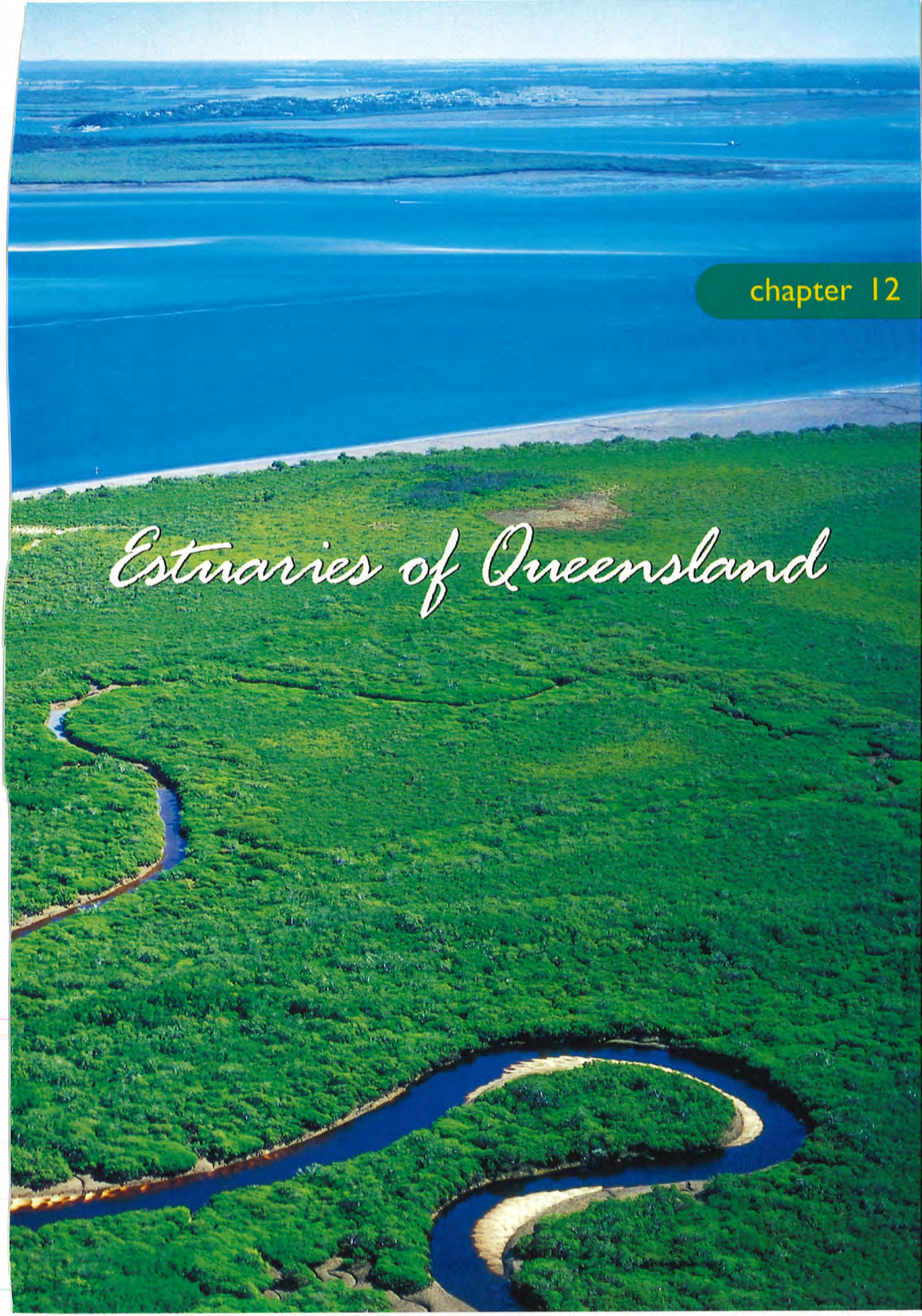
Public transport on Darwin Harbour (below)

Estuary management in the Northern Territory	
Management arrangements	Estuary Management responsibility falls on a number of agencies that operate Territory wide. The management of estuaries is affected by 22 Northern Territory Acts that deal with heritage, conservation, biodiversity, public health, fisheries, ports and chemicals, to name a few.
Key issues	• Maintence of the cultural, recreational and commercial value of estuaries • Scientifically credible monitoring of estuaries and catchments, as part of an adaptive natural resource management strategy • Protection and rehabilitation of remaining coastal wetlands • Communcate the condition of the estuaries to stakeholders and the public • Understand estuarine ecology to accurately predicate potential impacts, thereby avoiding unacceptable declines in estuary values • Stakeholder participation in estuarine management
Key management responsibility	The principle agencies include the: • **Department of Infrastructure, Planning and Environment (DIPE)** – planning developments, planning approvals, natural resource management, water quality, water resource planning, waste discharge licencing, waste management and pollution control, habitat mapping, management of coastal reserves, shoreline infrastructure • **Department of Business, Industry and Resource Development (DBIRD)** – fisheries, and in partnership with the Australian Quarantine Inspection Service, marine pest management
Policy and legislation	• ***Water Act 1992*** – has the most direct involvement on water quality issues in fresh and marine waters • ***Planning Act 1999*** and ***Waste Management and Pollution Control Act 1998*** are important acts that affect land use and waste management, respectively, in the catchment. • Relevant Commonwealth legislation, specific to the Northern Territory, is the ***Aboriginal Land Rights (Northern Territory) Act 1976***, under which freehold title to land, including estuaries, is granted to Indigenous occupants. • The declaration of **Beneficial Uses** (environmental values) for estuarine and catchment waters is the primary policy driver. • Beneficial Uses have been declared for Darwin Harbour and its major waterways (Darwin, Blackmore, Elizabeth, Howard Rivers), Fogg Bay, Gove Harbour, the McArthur River, Shoal Bay, Vernon Islands and Groote Eylandt. The uses include aquatic ecosystem protection, recreational water quality and aesthetics. • A **Plan of Management for Darwin Harbour** has been developed, in consultation with the community. The plan provides a strategy to maintain the values of the Harbour. • A **Northern Territory Coastal Marine Policy** is currently under review in consultation with stakeholders. • The **management of mangroves in the Northern Territory**, with special mention of Darwin Harbour, was reported on in 2002. • In 2003, 46,516 ha of mangroves, saltflats, mudflats and fringing vegetation in Darwin Harbour were zoned conservation areas under an amendment to the NT Planning Scheme. This includes 95.6% of mangrove communities in the harbour. • DBIRD implements **exclusion zones** for the protection of coastal habitat and the commercial fisheries.
Community initiatives	• **Waterwatch, Bushcare, Landcare** and **Coastcare** are raising awareness of catchment activities that affect estuarine health. In 2001 and 2002, the community participated in a mangrove monitoring program.



chapter 12

Estuaries of Queensland




Gulf of Carpentaria
919 Mitchell River
920 Coleman River
921 Holroyd River
922 Archer River
923 Watson River
924 Embley River
925 Wenlock River
926 Ducie River
927 Jardine River
928 Torres Strait Islands
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Gulf of Carpentaria
909 Calvert River
910 Settlement Creek
911 Mornington Island
912 Nicholson River
913 Leichhardt River
914 Morning Inlet
915 Flinders River
916 Norman River
917 Gilbert River
918 Staaten River

Queensland estuaries are diverse. They vary markedly in surrounding land use, in climatic influences and in the catchment size of rivers flowing into them. Unique and valuable marine environments such as the Great Barrier Reef and Moreton Bay are at risk from nutrients and sediments delivered by their adjoining estuaries. Estuarine values need to be better reflected in state and local government planning schemes. The links between catchment and estuary health must be understood and their management integrated, especially within water resource allocation processes.

Estuaries are important in Queensland life. They are valued for recreational and commercial opportunities and contribute greatly to our quality of life. Estuaries provide both natural assets, such as breeding and feeding habitats for birds, fish and other native animals, and capital assets, such as sheltered deep waters for shipping and port facilities. The value of Queensland estuaries is hard to determine due to the difficulty of putting a price on non-utilitarian aspects, such as scenic value. Calculating their commercial value is somewhat easier. Prawn, barramundi and mudcrab fisheries are major estuary-dependent industries in Queensland. Estuaries must remain near-pristine for their survival.

Royal Spoonbills, Woodgate National Park

More research into Queensland estuaries is urgently needed. We lack understanding of estuarine and marine flora and fauna and the effects of increased sediment and nutrient levels on them. Our knowledge of estuarine condition and variability, including the effects of episodic events such as cyclones, must improve so we can better manage this highly important resource for all Queenslanders.

Regions

- ***Gulf of Carpentaria***

  (from the NT border to Jardine River)

- ***Eastern Cape York***

  (from Kennedy Inlet to Annan River)

- ***Wet Tropics***

  (from Bauer Inlet to Herbert River)

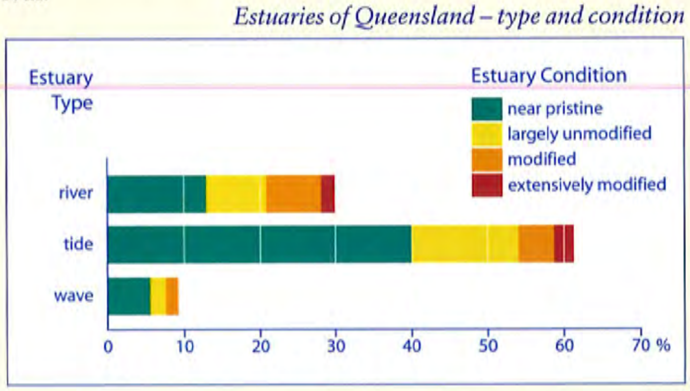
- ***Central Queensland***

  (from Gentle Annie Creek to Fitzroy River)

- ***South East Queensland***

  (from The Narrows to Currumbin Creek)

Estuaries of Queensland – type and condition



Gulf of Carpentaria

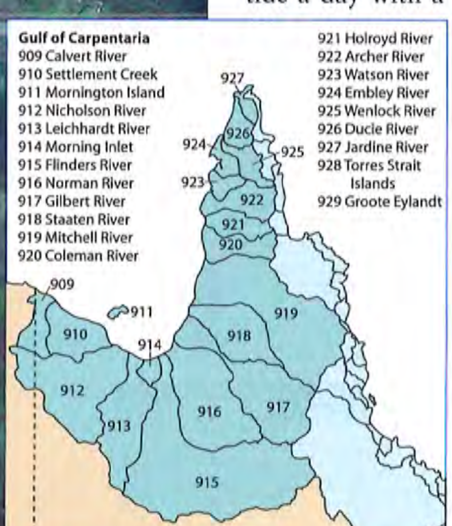
The coast of the Gulf of Carpentaria is probably the most uninteresting portion of Australia, looked at from an artistic point of view. On the eastern side it presents, with the exception of Duyfken Point, an almost unbroken line of low, swampy shores bordered by mangrove-trees.

The Picturesque Atlas of Australasia, 1886

Expansive floodplains

Estuaries from the Northern Territory border to the tip of Cape York typically have extreme wet and dry seasons and large floodplains. Catchments are flat and mostly vegetated with dry savanna woodlands. Rainfall is moderate (800 to 1200 mm) but highly variable. Almost all rain comes with summer monsoons from December to February. Rainfall decreases and river flow is more intermittent north to south. Tropical cyclones occur. Many form within the gulf but they are rarely as destructive as Coral Sea cyclones. Tidal energy is important in shaping estuaries with extensive tidal flats along the flat, muddy coastline. In the wet, rivers spread across vast floodplains.

The Gulf of Carpentaria has a complex tide pattern. There is usually only one tide a day with a range of one to two metres but height predictions can be unreliable and are strongly dependant on winds. Because the gulf is shallow, seas are often choppy. Shallow sand, mud and rock bars are common at the entrances to rivers and creeks.

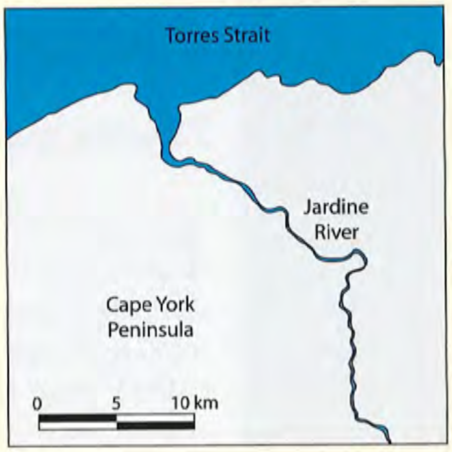


The gulf has diverse and abundant seagrass communities, providing habitat for many species, including juvenile commercial prawns. While most seagrass communities here are in shallow marine waters, particularly in the south and west, small patches of seagrass are found in many estuaries north of Archer Bay in the eastern gulf. Mangrove diversity is low compared to eastern Cape York and the northern coast of the Territory due to the seasonality of the region. Fringing mangrove forests are critical habitat for part of the banana prawn lifecycle. Estuarine crocodiles inhabit most gulf rivers and estuaries. Estuarine fishes are abundant and wet season flushes bring large sea fishes such as queenfish, trevally and king salmon into estuaries to feed.

Mining and grazing

Grazing is the main land use in the gulf catchments. Indigenous, recreational and commercial fishing occur in many estuaries. Estuaries are mostly near-pristine in condition with natural vegetation dominating catchments. Barramundi support a huge recreational fishery, though recreational fishing pressure (except near Weipa and Karumba) is less than on eastern Cape York. Mining is also an important land use with many of the cattle and minerals being exported through Karumba.

Case study: Jardine River



The Jardine River estuary opens to the Arafura Sea on the western tip of Cape York Peninsula. The Jardine is Queensland's largest perennially flowing watercourse despite the highly variable climate. Most of the catchment is porous sand and sandstone, forming an aquifer that maintains flow in the river throughout the dry months. To the west of the river, the waters feed a vast, swampy wetland complex into which salt water intrudes up to 10 km. Tidal range is high (about 4 m) and its influence extends about 9 km up-river.

Near the mouth of the estuary, the coast forms a series of sandy ridges stabilised by vegetation with swampy areas between. Exposed ridges are dominated by casuarina and grevillea woodlands with melaleuca woodlands in swampy parts.

Vegetation in the catchment and floodplain is complex, ranging from tropical rainforest on deeper sands to melaleuca woodlands, heathland, eucalypt forest and large areas of sedgeland, often with emergent shrubs. Freshwater mangroves and woody climbing vines are common along streams, as are patches of gallery rainforest. Mangroves and saltflats occur in the tidal reaches. Mangroves, though restricted in area, are diverse, with 30 species recorded in the estuary. Because salt water intrudes far into the Jardine swamps, species characteristic of mangroves are often found in association with those more typical of freshwater swamps. There are small areas of seagrass in the estuary mouth. Fauna is diverse due to the variety of habitats. Jardine River wetlands support estuarine crocodiles.

Most of the area is Aboriginal land, with a small amount under mining tenure. Much of the catchment has been dedicated as national park. The Jardine remains in near-pristine condition, with Aboriginal use and conservation management of the national park the main uses. The area is accessible only in the dry season. The estuary is a popular site for recreational fishing. Fishing charters target species such as barramundi and mangrove jack. There has been some erosion of the Jardine River bank at the Peninsula Developmental Road crossing, and some associated pollution.

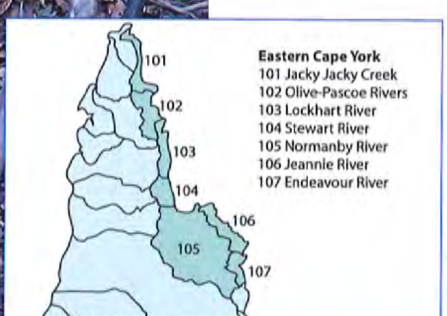
Eastern Cape York

Diverse productive mangroves

Except for the Normanby, estuaries on eastern Cape York tend to have short, coastal catchments and highly seasonal rainfall, ranging from around 1200 to 1800 mm per year. Rainfall is lowest around Princess Charlotte Bay.

Cape York estuaries are typically highly turbid with strong currents, due to tidal and river influences. Many have some freshwater input most of the year with considerable seasonal variability in the extent of freshwater influence along the estuary. Salinity can vary from near zero during the wet season to that of seawater (or even saltier) in the dry.

Cape York estuaries are typically fringed by diverse and productive tropical mangroves. These form zones both laterally and along the estuary. *Rhizophora* species often dominate the foreshore,with *Ceriops* species and *Avicennia marina* behind. River systems with substantial freshwater input support a number of mangrove species and rainforest trees. In all, 37 species of mangrove occur in the Cape. Many Cape York estuaries have 20 to 30 species.



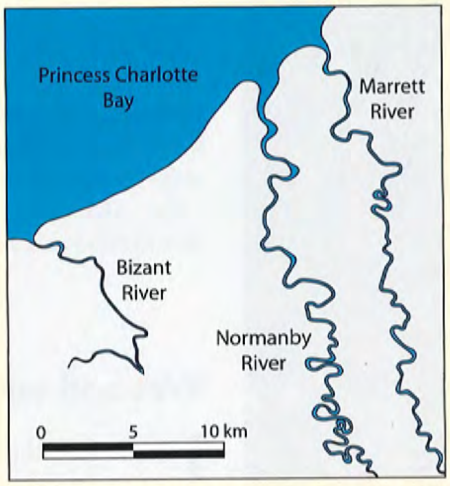
These estuaries are naturally productive, with abundant phytoplankton. Fish such as barramundi, mangrove jack, fingermark and estuary cod are common. Pelagic species such as giant trevally and queenfish patrol estuary mouths feeding on baitfish pushed out by wet season flows.

*Ant plant (*Myrmecodium sp.*) in Lockhart River Mangroves*

Overgrazing

Estuaries on Cape York are mostly near-pristine. Catchment clearing is minor at present. Most catchments are used for cattle grazing which has significant impacts on rivers, especially floodplains and freshwater wetlands, but less direct impact on estuaries, although sedimentation may occur in some systems. Tourism is increasing. Four-wheel drive access and camping activities are likely to have local impacts. The estuaries are fished both commercially and recreationally.

Case study: Normanby River



The estuary of the Normanby River forms a sinuous green line as it snakes northward through the saltflat and savanna country on the eastern side of Princess Charlotte Bay. It drains a relatively large catchment of some 24,000 km², about 20 percent of which forms the Lakefield National Park, with its vast, seasonally inundated wetland areas. Most of the remaining catchment area is used for grazing.

The estuary is more or less funnel shaped, decreasing in width from around 150 m at the mouth to 55 m at 25 km upstream. The tidal reaches of the river are approximately 80 km long, and fringed with mangroves for some 48 km from the mouth.

The estuary is in near-pristine condition, and is naturally turbid (suspended sediment concentrations: 150–200 mg/L) due to tidal resuspension of sediments. Tidal range is about two metres, and the tides are semi-diurnal. Average annual rainfall is relatively high, but is seasonal and freshwater discharge is usually restricted to the December to March period. During the wet season, huge areas of floodplain can be inundated and the estuary often runs fresh to the mouth but as the rainfall drops away, the freshwater influence retreats up the estuary such that brackish water can penetrate more than 50 km upstream during the dry season. High evaporation rates can lead to hypersaline conditions in the estuary during drought years.

The estuary floor is a thin silt or sand layer overlaying harder sediments. The banks are steep, unconsolidated and muddy and are subject to episodic slumping. The mangrove fringe is narrow along most of the estuary but increases in width to tens of metres on the inside of actively migrating meanders. Like most Cape York estuaries, the Normanby River has a diverse mangrove community, with at least 21 species of mangroves present.

Lakefield National Park

Wet Tropics

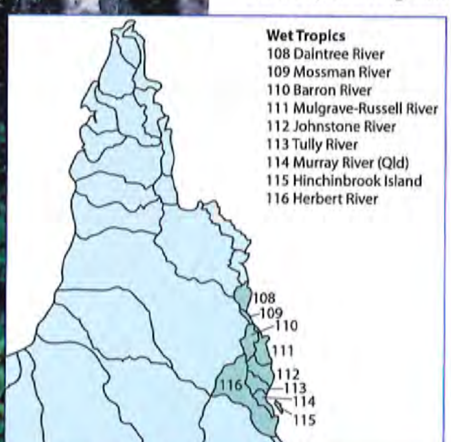
The coastal country, proceeding northward [from Port Douglas], is beautiful as viewed from the sea, but detailed description would be somewhat monotonous. The main range is ever in view, here approaching the ocean and dipping abruptly into the water; there receding in long curves enclosing tracts of country where a deep soil of detritus nourishes a wealth of tropical vegetation.

The Picturesque Atlas of Australasia, 1886

Wet and wild

In this region the Great Dividing Range comes close to the coast, which runs in a sufficiently northerly direction that the southeast trade winds bring moist air onshore. These factors combine to make the Wet Tropics region the wettest in Australia with rainfall over much of the area exceeding 2000 mm per year. Wetter still are several coastal areas (e.g. Tully, 4300 mm) and the ranges (e.g. Mt Bellenden Ker, 8529 mm). These high rainfall areas usually experience year-round freshwater flow to estuaries in spite of a strong wet–dry distinction. There is great diversity in the way these estuaries function with most being tide-dominated and having significant river input. Typically, waterways are characterised by steep catchments and short estuaries. Tropical cyclones may affect the area and may be very strong and severe.

Lizard Island National Park



Mangrove communities are diverse and well developed, often grading into rainforest and sharing species at the interface. Structural similarities with rainforest include an abundance of epiphytes including the ant plant *Myrmecodia beccarii*. Extensive areas of freshwater wetlands, such as melaleuca forests, palm swamps and open sedge swamps, formerly characterised floodplain areas, though these have largely been 're-claimed' for agriculture. Seagrass beds are associated with several estuaries in the region (within or in shallow water near the mouth of the estuary) though seagrass distribution is limited by the naturally turbid nature of these systems and diversity is relatively low compared to many offshore seagrass habitats in northern Australia. Seagrass beds in the Hinchinbrook channel are important as food for dugong and turtle populations.

Tourists and sugar

The impenetrable rainforests, and determined resistance from the local Indigenous peoples, restricted European settlement of the Wet Tropics until the latter half of the 19th century. The discovery of gold in the 1870s triggered the expansion of settlements in the area, leading to the formation of towns such as Cairns and Innisfail. The rich soils of the coastal plain were soon found to be suitable for sugar growing and the industry expanded rapidly using 'Kanaka' South Sea Islanders as a source of cheap labour. Several waves of migration from Europe and Asia led to the growth of a diverse community with a frontier mentality, intent on pushing back the boundaries of the 'scrub' as the region was opened up for agriculture. The recognition of the Wet Tropics as an area of outstanding natural beauty and of scientific and conservation significance has seen the region enter a new era in the latter part of the 20th century. The introduction of fast catamarans and wave-piercing vessels facilitated the development of mass tourism to the Great Barrier Reef and the World Heritage listing of the region's tropical rainforests focussed interest on the natural features inland, resulting in continuing development of the region as an international tourist destination.

Cane run-off

Sugar cane farming is the main land use in the region south of the Daintree. These estuaries are predominantly in near-pristine to largely unmodified condition. Clearing is a significant issue, with loss of riparian vegetation contributing to increasing sediment loads instream and to significant fish habitat modification. Commercial fishing, and more recently aquaculture, also play an important part in the region's economy. Today, sugar dominates the coastal plain but production of bananas is also considerable while tea, pawpaws and numerous tropical fruits are also grown.

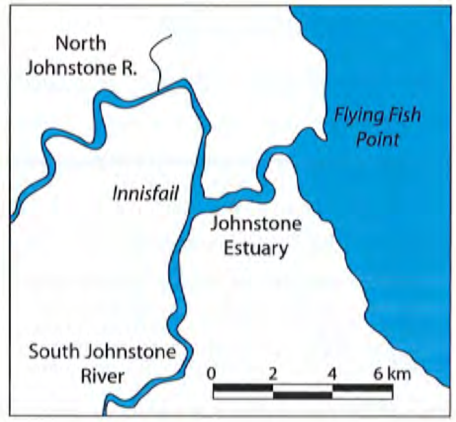
Monitoring nutrient concentrations in streams draining sugar-cane-cultivated land in the Tully, Johnstone and Herbert catchments has shown elevated levels of nitrogen. Although farmers have made attempts to minimise the amounts fertiliser run-off by reducing the total amounts used on their crops, the large increase in area under sugar cane cultivation has offset any overall reduction in stream nitrogen levels. The rate of nitrate leaching from banana cultivation is much greater than that of sugar cane, as banana crops need on average three times more nitrogen fertiliser. It appears likely that the increased nitrogen levels observed in the Tully, Johnstone and Herbert catchments are a result of the increased agricultural activity.

Daintree mangroves (above); Harvesting sugar cane near Cairns (below)

Case study: Johnstone River

The Johnstone River, discharging into Glady Inlet, has a very shallow bar, but is navigable for some eight miles for small craft. The little settlement of Geraldton [Innisfail] *is situated on this rivulet.*

The Picturesque Atlas of Australasia, 1886



The estuary of the Johnstone River lies on the coastal plain in one of the wettest areas of the north tropical coast. Severe flooding is not uncommon in the lower Johnstone, particularly when associated with tropical cyclones. The town of Innisfail (population 9000), located on the estuary at the junction of the North and South Johnstone rivers, receives some 4 m of rainfall per year and vies with nearby Tully for the 'golden gumboot award' for the wettest town in Australia. The town grew as a centre for the expanding sugar industry in the early 20th century. The majority of the Johnstone floodplain has been cleared for sugar cane and more recently extensive banana plantations. It is therefore not surprising that the main industry in the region is sugar production and milling, though game and reef fishing also form a significant part of the local economy.

The headwaters of the North and South Johnstone Rivers flow through agricultural and dairying areas on the Atherton Tablelands, before cascading down through heavily forested upland areas and steep gorges to the coastal plain. The total catchment area is 1680 km^2, approximately 43 percent of which is in protected areas, including World Heritage rainforest. Riparian vegetation has for the most part been reduced to a narrow strip in the lower reaches of the rivers, though a number of healthy mangrove areas remain in the estuarine section. In all, a study on the riparian zone found that 116 sites (60%) inspected in the catchment were in poor or very poor condition. In addition, about 60 percent of coastal wetlands have been lost from the Johnstone River floodplain over the past 50 years, especially freshwater melaleuca wetlands. In contrast, mangroves increased in area by almost 15 percent from 1951 to 1992, effectively capturing and colonising new areas of sediment derived from catchment erosion.

The Johnstone River mouth, opposite Flying Fish Point

Moored trawlers, Innisfail

Urban and industrial development in the region has been minimal, resulting in few point sources of pollution. The relatively high nutrient levels in the estuary mostly come from catchment sources (run-off from the cane, banana and dairy industries), though the small proportion delivered from the Innisfail sewage treatment plant via Ninds Creek may be relevant during periods of lower flow. Extensive in-stream water quality monitoring of the Johnstone River and tributaries has estimated that on average about 1830 tonnes of nitrogen and 360 tonnes of phosphorus are released into the sea annually. The North and South Johnstone rivers have a combined annual run-off of approximately 2.7 million megalitres. The South Johnstone and Mourilyan sugar mills are the major industrial water extraction sites while approximately 5160 ha of crops are irrigated from surface water of the Johnstone River. Annually, about 3200 megalitres of water is extracted for residential use.

A biological study of river health using macroinvertebrates as indicators found that overall, the Johnstone River seems to be in moderate-to-good condition, though some sites were in poor condition. It is not surprising that the rainforest areas with good riparian vegetation and diverse in-stream habitats were in the best condition. Whereas, the smaller tributaries located in agricultural and grazing areas were in the poorest condition as they had little riparian vegetation, high weed infestations, poor in-stream habitat and poor water quality.

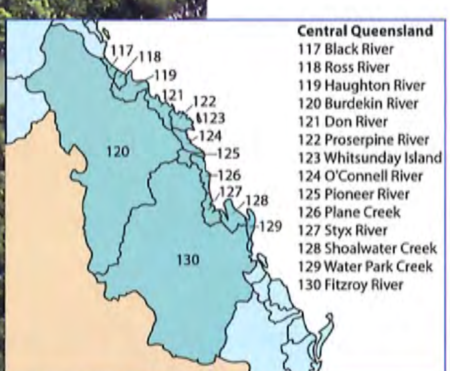
The Johnstone River estuary is an important recreational area for the people of Innisfail, particularly for fishing. The waters of the estuary and the adjacent Great Barrier Reef also support a substantial commercial fishing fleet. At least 88 species of fish are found in the Johnstone River estuary including species such as sand whiting, large banded grunter, silver and pikey bream, dusky flathead, barramundi and mangrove jack. Prawns are caught by beam trawl from seagrass beds in the estuary.

The shallow nature of the river entrance has prevented development as a port. A bulk sugar terminal was constructed at nearby Mourilyan Harbour to service the sugar industry.

Central Queensland

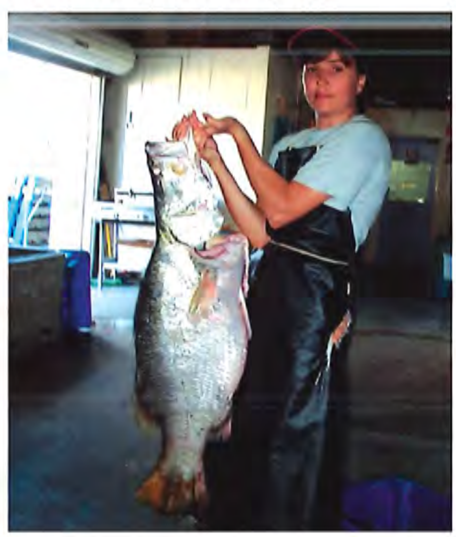
Great Barrier Reef, (Occasionally) Great Big Rivers

Catchments south of Ingham down to Port Curtis typically have strongly seasonal rainfall and are much drier than those further north. Average annual rainfall in the region is moderate (generally 800 to 1400 mm along the coast), but rainfall is highly seasonal with large inter-annual variation and changes considerably according to local topography. The dry season is frequently close to a complete drought in many areas, and the larger rivers drain catchments that extend to much drier areas inland. The central Queensland coast is vulnerable to tropical cyclones, particularly in the northern half of the region. There is great diversity in the way that these estuaries function with tidal and river energy being significant for most estuaries. The floodplains of these systems are larger than in the wet tropics and two large river basins, the Fitzroy and the Burdekin, drain extensive inland areas.



Beef or barra?

Rockhampton is known as the beef capital of Australia, though the barramundi is also an icon of the city. Some of the best barramundi fishing occurs within the city reaches of the Fitzroy River, which is said by locals to be the 'best kept fishing secret in Queensland'. Blue threadfin, king threadfin and gold spot estuary cod are also caught in the region.



From 'soil' to 'sediment': ponded pastures

The estuaries of central Queensland are predominantly in largely unmodified and modified condition. Agriculture (grazing, irrigation, sugar cane, cropping) is the main land use and occurs over much of the low-lying alluvial areas. Intensive sugar cane production dominates the agriculture of the northern region. Beef cattle grazing occurs on coastal plain and inland areas not used for crops. The major urban centres in the region are Mackay, Rockhampton, Gladstone and Bundaberg.

Mackay (population 44,880), on the Pioneer River, is a centre for sugar production. It has a relatively high annual rainfall (1650 mm) and a moist/humid climate.

Located on the Fitzroy River, Rockhampton (population 57,770) is the self-proclaimed 'beef capital of Queensland'. It has significantly less rainfall (900 mm) and is a unique combination of country, city and coast. Tourism is increasing in both centres, which serve as gateways to the Great Barrier Reef.

Prawn aquaculture occurs on tidal flats in the Burdekin delta and other places within the region. Future expansion of this industry is proposed. Hydrology of the Burdekin delta has been modified by the operation of an artificial aquifer recharge pumping program that diverts water from the main Burdekin River channel down the distributary channels including Plantation and Sheepstation creeks. Nutrient inputs have contributed to the eutrophication of freshwater wetlands and assisted the domination of exotic pasture grass species. Stock dams constructed on the lower reaches of coastal plain drainage depressions have altered the hydrology and salinity regime by preventing the inflow of high spring tides and have promoted the growth of ponded pasture species to the detriment of native sedge communities. On levee areas, a high frequency of intense fires associated with cane burning has encouraged fire-loving exotic grasses. This, combined with the invasion of rubber vine, has caused major disturbance to streamside vegetation communities. Acid drainage problems have been reported for some lower distributary channels of the delta. Marine and coastal wetland habitats remain relatively undisturbed and retain high habitat values. Recreational usage of mangroves and the foreshore area is also significant.

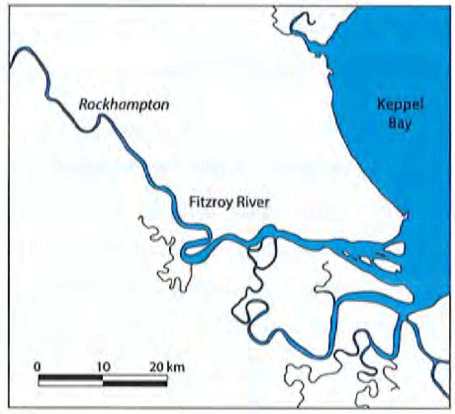
The region supports a mixed fishery with species caught including mudcrab, shark, banana prawns, tiger prawns, greasyback prawns, mullet, spanner-crab, king salmon and barramundi.

Shute Harbour near Proserpine (facing page, top); Coastal CRC researcher with a Fitzroy River barramundi (facing page, bottom); Customs House, Rockhampton, on the Fitzroy River (below)

Case Study: Fitzroy River

A light-house now crowns the bluff, and constitutes a leading landmark, signalising approach to Keppel Bay, into which the great Fitzroy River – formed by the union of the Mackenzie and the Dawson with their network of tributary streams, draining the whole of the Leichhardt district – discharges its burden of turbid waters.

The Picturesque Atlas of Australasia, 1886



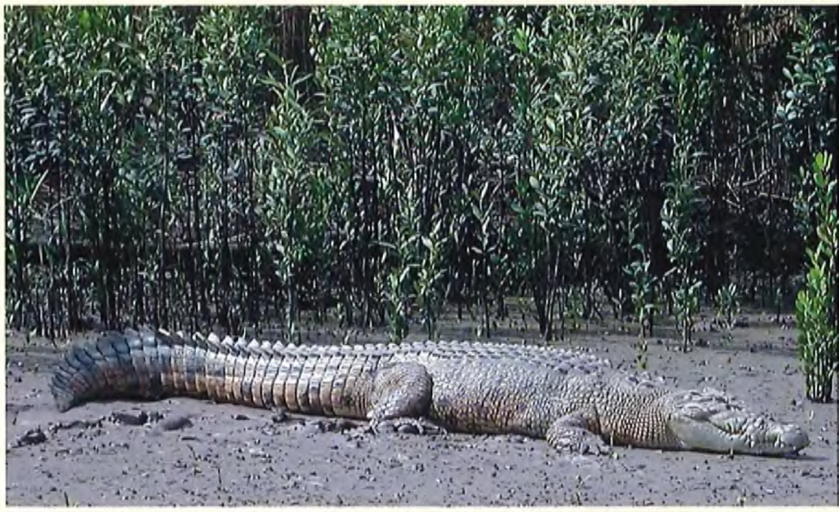
The catchment of the Fitzroy River estuary is the second largest in Australia, covering nearly 150,000 km^2 of central Queensland – one-tenth of Queensland. Freshwater flow is highly episodic due to the unpredictable rainfall, with the majority of flow occurring in summer. The river delivers in the order of 5 million tonnes of sediment to the estuary each year. Water quality can vary from poor to good depending on seasonal flow conditions and inputs from human activities. The lower estuary experiences very high turbidity due to tidally suspended sediments (tidal range of 0.3 to 4 m). Periodically pesticide and nutrient levels are high. There are occasional phytoplankton blooms.

Aquatic biodiversity of the Fitzroy region reflects a unique blend of both tropical and temperate species as well as supporting several endemic (unique to the area) species. Species have adapted to the extreme variability in riverine and coastal conditions related to episodic climate events. In many cases, connections between marine, freshwater and wetland habitats are vital to the life cycles and productivity of natural populations. Good water quality supports both aquatic biodiversity and human uses of the region's waterways.

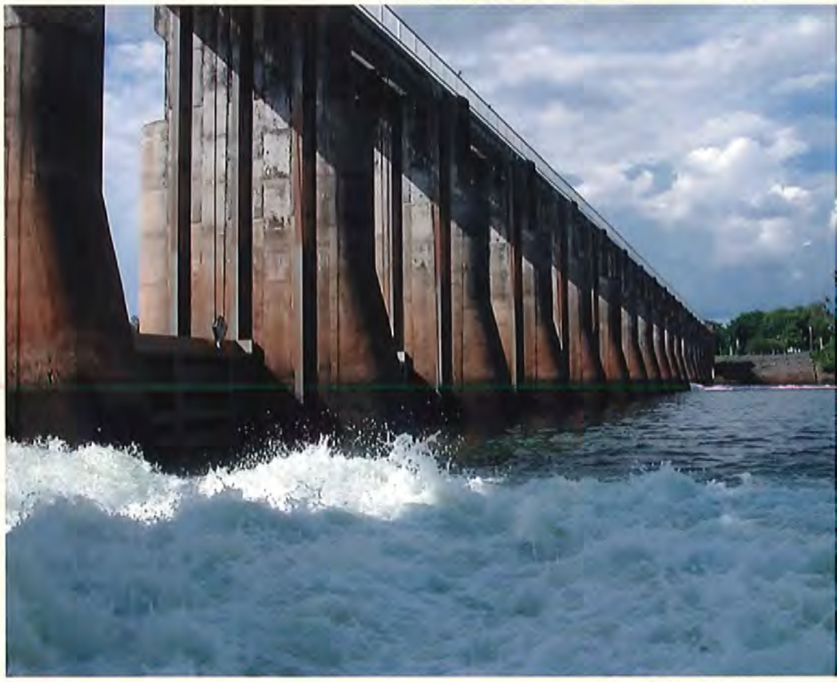
Extensive floodplain and riparian areas are degraded or threatened due to clearing and invasion by exotic species including ponded pastures. Catchment land use is dominated by agriculture (grazing, dryland cropping, irrigated cotton and horticulture) and mining (coal production of 100 million tonnes/year, magnesite, nickel and, historically, gold and silver). Grazing occurs over the majority of the catchment (more than 130,000 km^2) and although off-site impacts are likely to be small on a per hectare basis, grazing is possibly the largest contributor to water quality problems in the estuary due to the massive area involved. Dryland cropping (0.8 to 1 million ha) contributes large amounts of sediment in run-off especially when cropping land lies fallow, and thus vulnerable to soil erosion, for long periods. Irrigated cropping, although small in area (45,000 ha) relative to the size of the catchment, is resource intensive and may contribute high levels of nutrients and pesticides. Extracting water for irrigation also reduces freshwater flow to the estuary.

Much of the lower catchment has been cleared for grazing and urban development, although a large area of intact mangrove forest and saltmarshes remains near the southern mouth. In general the lower reaches of the estuary appear to be in good condition, though with high turbidity.

Upstream, near Rockhampton, nutrient levels are high due to catchment inputs combined with local sewage outfalls. High nutrient levels are exacerbated by a barrage (built in 1970 to provide a water supply for the city) which reduces tidal mixing. Until 1995, the barrage also prevented the migration of fish, including barramundi, between the fresh- and salt-water reaches of the river. Construction of numerous smaller barrages across creeks and wetlands for cattle watering and grazing, as well as significant ponded pasture infrastructure, has reduced the access to these areas for fish and other species.



Commercial fisheries for barramundi, threadfin salmon and mudcrabs (and others) are significant by state standards. There appears to be a downward trend in the barramundi catch since the 1950s. Recent research confirms anecdotal evidence that recruitment rates and abundance of adult fish are strongly related to floods in the catchment. Keppel Bay supports a major scallop, prawn and fish industry.



Keppel Bay has blooms of *Lyngbya* and *Trichodesmium* cyanobacteria in certain seasons. While these have been considered natural phenomena, it is known from chlorophyll monitoring that the region has a high algal (primary productivity) capacity.

Recent research by the Fitzroy Coastal CRC group has found that saltwater crocodile eggs have elevated levels of pesticide residues, the result of bioaccumulation through the food chain.

The Fitzroy River, Rockhampton (facing page)

The salt water crocodile is at the southern limit of its breeding range in the Fitzroy estuary (top right)

The barrage has reduced tidal mixing in the estuary (bottom right)

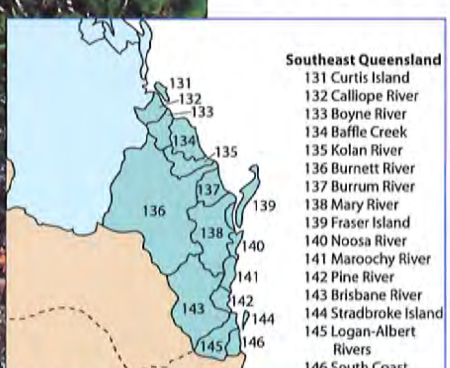
South East Queensland

A perfect climate

Catchments from Port Curtis to the New South Wales border are less seasonal than elsewhere in Queensland. Rainfall in most areas is moderate to heavy, in the 1000 to 1600 mm range, and higher in several areas such as the Lamington Plateau and the ranges of the Sunshine Coast hinterland, which are cloaked in subtropical rainforest. Rainfall can occur year round, but the summer and autumn months are considerably wetter, and storms are a relatively frequent occurrence in late spring and summer. There is great diversity in the way estuaries function in this region.

A population explosion

South east Queensland is one of the fastest growing areas in Australia. Rapid population growth has been occurring for the past 20 years and continues – currently at about 1000 people per week. About half of this growth is interstate migration, driven by attraction to the climate, natural environment and quality of life. The regional population of 2.2 million (at the 1996 census) is predicted to increase to over 3 million by 2011. Unless action is taken to reduce impacts of urban development this increase will bring great pressure on the waterways of the area.



Less noticeable, but more important than the increase in population is the increase in the ecological footprint of that population – the amount of productive land and water it takes to provide all the resources it consumes and to take in all the waste it makes. In south east Queensland this includes new land for landfills, waterways impacted by urban and industrial effluent, the effects of expanding port facilities and increased pressure on agricultural land and commercial fish stocks – in the region or elsewhere.

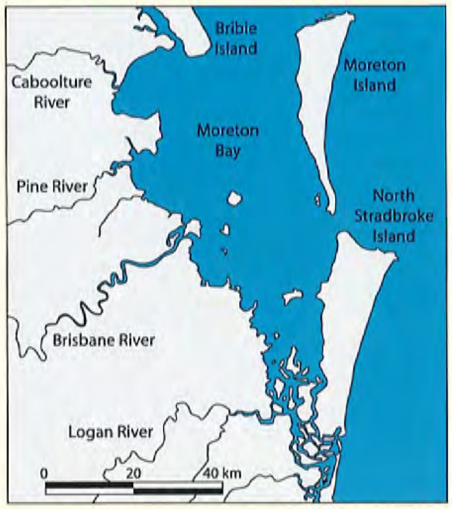
Growing pains

Land from Noosa south is generally highly urbanised and developed, and with all the problems associated with intensive use flowing on to the estuaries. The estuaries are predominantly in modified to extensively modified condition.

Commercial species from the region include mackerel, blue swimmer crab, scallop, mullet, whiting (from Hervey Bay); mullet, whiting, mud crabs, garfish, bream, flathead (from Great Sandy Strait); and mullet, bay prawns, banana prawns, blue swimmer crab, flathead, whiting, Moreton Bay bugs.

Case study: Moreton Bay

Moreton Bay, known to its Indigenous inhabitants as *Quandamooka*, is a mosaic of degraded and healthy ecosystems. One of the largest estuarine bays in Australia, it is enclosed in the north and east by the dune barrier islands, Bribie, Moreton, and North and South Stradbroke. The bay is roughly wedge-shaped, and opens out towards the north where most ocean flushing occurs through North Passage between Bribie and Moreton islands. The southern bay is a network of channels that weave around a series of low-lying islands, fringed by mangroves and saltmarshes. The mouth of the Brisbane River and the shipping lanes to the northern end of Moreton Bay are dredged for the Port of Brisbane.



A range of habitat types are found within the bay including saltmarshes, saltflats, intertidal mudbanks and sandbanks, mangroves, seagrass, corals, rocky shores, and sandy beaches. Moreton Bay is an important overlap zone for plant and animal species with tropical and temperate affinities. It is also a summer feeding ground for wader birds that migrate down the Australasian flyway from the northern hemisphere. The bay was declared a Marine Park in 1993 and is listed as a wetland of international importance under the Ramsar convention. Large populations of turtles and dugongs feed on seagrass beds at Amity and Moreton banks in the eastern bay.

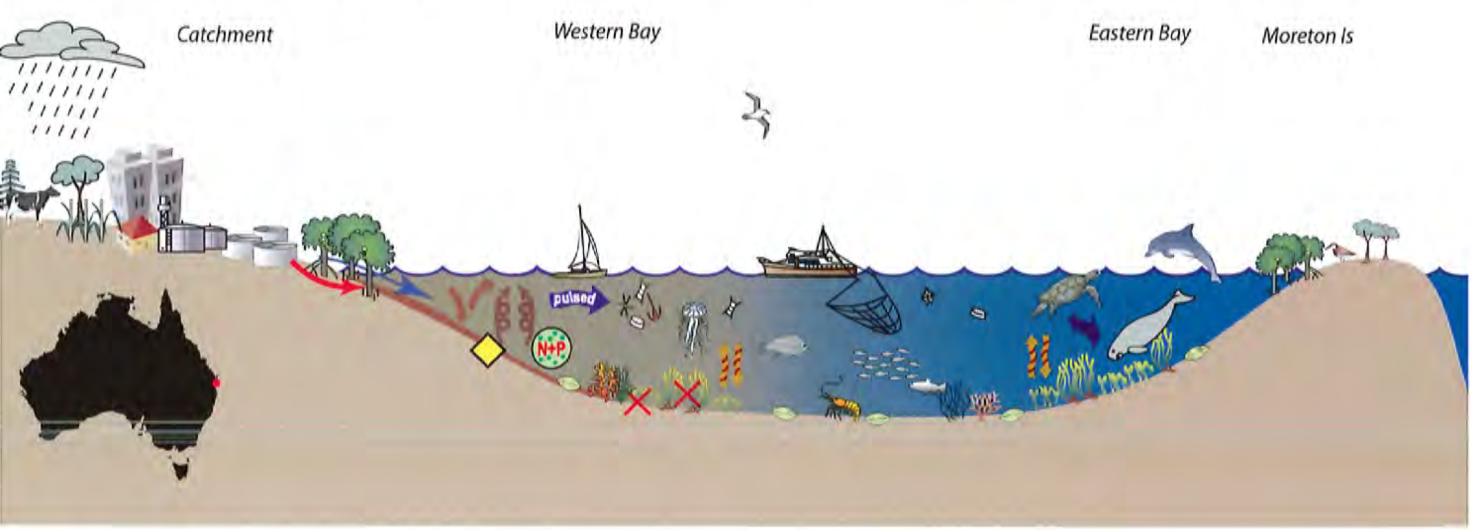
Mangroves, Redcliffe (below); the Brisbane River meanders through inner city suburbs (facing)

Pumicestone Passage at the northern extremity of Moreton Bay

Moreton Bay supports commercial prawning and fishing estimated at about 10 percent of the commercial catch for the entire east coast of Queensland. Many streams flow eastwards into the bay, including the Caboolture, Pine, Brisbane, Logan and Coomera rivers. All are heavily modified and polluted from a range of urban, industrial and rural point and diffuse sources such as stormwater, sewage and industrial discharges, grazing, cropping and aquaculture. Sediments and nutrients, particularly nitrogen, are the major pollutants. The eastern bay is subject to strong tidal mixing and flushing through the North and South passages and has good water quality (supporting oyster growing), sandy sediments and extensive, healthy seagrass beds. Fine-grained sediments accumulate in the western bay, where tidal mixing is much less pronounced and flushing is poor, particularly in the smaller embayments of Deception, Bramble and Waterloo bays.

Poor water quality has brought coral and seagrass loss to several areas in the western and southern bay, increased growth of macroalgae and occasional algal blooms. Efforts by local governments to reduce point-source pollution to the bay may be offset by the expansion of urban areas in the rapidly growing region.

- Heavy summer rain with episodic flooding
- Cropping in the catchment has led to increased sediment and nutrient loads
- Grazing in the catchment contributes to increased sediment and nutrient loads
- Queensland's biggest population centre is in the catchment
- Catchment delivers high sediment and nutrient levels in run-off
- Pine plantations in the northern catchment
- Industrial discharges from several rivers end up in Moreton Bay
- Effluent from several sewage treatment plants discharges into the bay
- Recreational and commercial fishing are important industries in Moreton Bay
- The bay is a haven for recreational boaties
- Trawling is the basis of major Moreton Bay fisheries
- N+P Nutrient concentrations are elevated near river plumes
- Moderate to high dieldrin levels are found in the western bay
- The eastern bay is well-flushed via north and south passages and Jumpinpin
- Tidal currents resuspend sediments in the Brisbane and other estuaries causing high turbidity in the western bay
- Desposition and scouring
- Sediment nutrient fluxes - nitrification and denitrification
- Six mangrove species occur in zones
- Phytoplankton blooms occur after pulsed rainfall and run-off
- Seagrass decline in the western bay is associated with river sediment plumes
- Lyngbya blooms
- Benthic microalgae are ubiquitous in the bay
- Seagrass distribution is influenced by grazing
- High nutrient levels lead to abundant growth of macroalgae in shallow areas
- Moreton Bay is internationally recognised habitat for migratory birds
- Aquatic macrophytes (e.g. seagrass) provide habitat for many species



Estuary management in Queensland	
Management arrangements	There is no formal coordination for estuary management in Queensland. The effort is dispersed through multiple agencies with responsibility for different aspects of estuary management.
Key issues	• Aquaculture is an emerging issue for Queensland's estuaries and will need to be well planned and managed. • Coastal development and pressures are increasing in relatively intact undeveloped areas. • River and catchment impacts on estuarine health and values need to be better managed. • Habitat loss was previously a big issue (1960s and 70s). Legislation has largely limited further removal of mangroves and other marine plants, however this may be placing increased pressure on other habitat types. Understanding these impacts is important.
Key management responsibility	Key state agencies involved in the management of estuaries include the: • **Department of Primary Industries and Fisheries (DPI&F)** – fisheries and fish habitat management (including Fish Habitat Areas and marine plants) • **Environmental Protection Agency (EPA)** – coastal planning, coastal processes, water quality, marine parks, licensing all discharges into waterways • **Department of Natural Resources, Mines and Energy (NRM&E)** – water resource planning • **Department of Local Government and Planning** – integrated planning
Policy and legislation	The EPA is coordinating the development of the **State Coastal Plan** and associated **Regional Coastal Plans**, which specifically include estuaries. Aspects of estuary management are also included in the: • ***Environmental Protection Act 1994*** and **Environmental Protection Policy (Water)** • ***Integrated Planning Act 1997*** • ***Fisheries Act 1994*** • **Rivers Policy** • **Local Government Strategic Planning**
Community initiatives	• The departments of Primary Industries and Fisheries, Natural Resources Mines and Energy, Environmental Protection Agency and Waterwatch Queensland, with funding support from the National Heritage Trust Coasts and Clean Seas program are developing **Community Monitoring Methods for Marine Environments** with a focus on estuarine and coastal areas. This complements the successfully established **Seagrass Watch** program operating in Hervey Bay and the Whitsundays. • Other community initatives include: **Waterwatch**, **Coastcare**, **Wader Birds**, **Sunfish**, and **Surfrider Foundation** groups and activities.

chapter 13

Looking back – moving forward

Photograph by W. Eugene Smith

In exploring Australia's estuaries state by state (Chapters 6–12) common threats to estuary health emerge. The majority of these issues arise from the way we interact with our estuaries and with the catchments that feed them, whether this interaction be as individuals or as a society. Often we are not even aware of the cumulative impacts of our daily actions. In Chapter 4 we investigated the connections between land use and estuary health.

Managing the threats to estuary health is complex and challenging but we are not alone in facing this problem. Estuaries around the world have been degraded by unsustainable land use practices and a growing world population. This chapter reflects on overseas experiences and then explores the issues facing Australia's estuaries and the way forward.

Looking back: Lessons from the past

- *Mercury poisoning in Minamata Bay, Japan*
- *Salinisation in Mesopotamia, the Middle East*
- *The shrinking Nile Delta, Egypt*
- *A mixed blessing for Benoa Bay, Bali*
- *Poisoned – Ok Tedi and Fly rivers, Papua New Guinea; Tisza and Danube rivers, Europe*
- *Zebra mussels in the Great Lakes, North America*
- *The Río Colorado Delta, Mexico*
- *Fisheries decline in the Indus River Delta, Pakistan*

Already lame with Minamata disease, Yae Sato carries fresh fish home for her family's evening meal . (See pages 242 for the story of mercury contamination in Minamata Bay.)

Managing industrial discharges: Mercury poisoning in Minamata Bay, Japan

Minamata is a paradigm for informing an environmental ethos that treading lightly is advisable where consequences are unknown. Even so, no one can foretell the longer-term and sometimes undesirable consequences of an action, and we must cope with them as they emerge.

Douglas Allchin, University of Minnesota

Key lessons:

- *People are part of the environment. Contaminants in the environment affect our health.*
- *Environmental decisions should be based on the precautionary principal. Short-term profits may result in long term impacts.*
- *Early intervention to address warning signs may prevent bigger problems.*

Like Bhopal or Chernobyl, the name Minamata has become synonymous with environmental disaster. In the 1950s, a wave of scattered, apparently unconnected and mildly mysterious events began to haunt the town of Minamata in Japan. It started with cats 'dancing' oddly in the street and sometimes collapsing to die in evident pain. Then, in 1956, people started showing similar symptoms – slurred speech, stumbling, numbness of the hands and feet, problems with hearing and vision, and tremors and convulsions. Many people died and survivors were sometimes left with paralysed and contorted bodies. Later, many children were born deformed or brain damaged.

The cause of 'Minamata disease' was soon identified as heavy metal poisoning from eating the fish and shellfish of Minamata Bay. The Chisso Corporation, foundation of the town's economy, had been discharging organic mercury into the bay since the 1930s from an industrial plant that made plastics. Chisso and government officials took the position that, without conclusive proof of a cause, no effective public action could be taken. By 1959 the company's own research concluded that mercury from the plant caused Minamata disease but these results weren't made public and Chisso Corporation kept discharging mercury until 1966.

In fact, evidence of marine pollution was clear before people became sick. Fisheries were already in trouble and declining catches had seen Chisso pay retributions for damage to local fisheries as early as 1926. Eventually fishermen and disease victims won a series of court cases against the company and removal of contaminated sludge from the bay began in 1977. The local governor declared the mercury levels in fish and shellfish from Minamata Bay safe for consumption on 29 July, 1997. This was marked by the complete removal of a net that had for 23 years prevented mercury-polluted fish in the bay from entering the sea.

Photograph by W. Eugene Smith

Managing agricultural impacts: Salinisation in Mesopotamia, the Middle East

Irrigation has supported agriculture for 6000 years in Mesopotamia (what is now Iraq and part of Iran). In this dry region, surface water is supplied by just two major rivers, the Tigris and the Euphrates, which rise in the mountains of southeastern Turkey and follow almost parallel courses across most of present-day Iraq. The so-called Fertile Crescent between these rivers was one of the primary cradles of western civilisation. At various times the kingdoms of Babylon, Assyria and Sumer all occupied the region.

Accounts from pre-Biblical times tell of flowering oases, hanging gardens and lush fields of irrigated crops. Many irrigation techniques still used today were first developed in the region.

Although the plain of Mesopotamia is very flat, the Euphrates is slightly higher than the Tigris and floods in the Euphrates occasionally found their way across country into the Tigris. This gradient provided the basis for a flood irrigation system using Euphrates water as the supply and the Tigris channel as a drain. Although irrigation allowed the cultivation of food crops in this arid region, the Mesopotamian civilisations always had persistent problems with poor soil, drought, catastrophic flooding, silting and soil salinity.

The Tigris and Euphrates have dramatic spring floods, from snowmelt in the highlands of Anatolia. They deposit abundant silt on the flat and poorly drained plains. Silt accumulated quickly in the irrigation canals, a problem which could be overcome by constant dredging as long as organisation and labour were available. The problem of salinity, however, was more insidious.

Because water was difficult to drain off the fields, there was always a tendency for salt to build up in the soil as water evaporated. Application of more water to leach out the salts simply waterlogged the soil, increasing the salt concentration and bringing the salts closer to the surface. As salt deposits began to bloom over the soil surface, they poisoned the soil and rendered it unsuitable for any human use. Despite their initial success in bringing the desert to life, the great Mesopotamian civilisations fell one after another and today most of the area is barren. Iraq is a relatively poor nation. Little of its land is arable – even with extensive irrigation. The recovery time from salinisation is variable but is almost certainly on a geologic, rather than human, timescale.

Key lessons:

- *Altering one component of the landscape alters all others. Changes in hydrology may have longlasting unintended consequences.*
- *To ensure we can feed everyone on Earth in the longer term a change in emphasis is required – from production to sustainability.*

Managing environmental flows: The shrinking Nile Delta, Egypt

Key lesson:

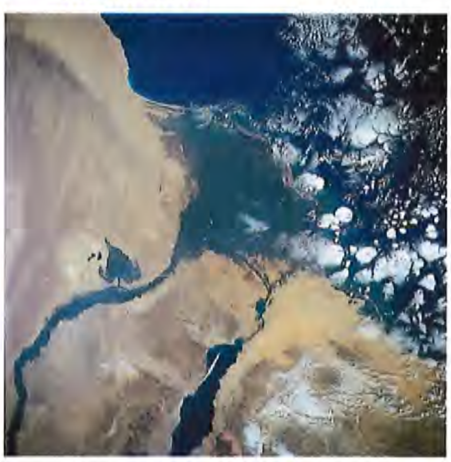
- ***Environmental flows are essential for healthy estuaries, maintaining biodiversity and productivity.***

Since the completion of the Aswan High Dam on the Nile River in Egypt in 1971, the river's floodplain and delta have undergone significant changes. The dam captures the world's longest river in the world's third largest reservoir, Lake Nasser, to provide water for irrigation, flood control and hydroelectricity.

Prior to the dam's construction, annual floods would deposit some 10 million tonnes of nutrient-rich sediment in a thin layer over the floodplain and delta, into which farmers planted their crops. The delta was gradually expanding into the Mediterranean Sea. Organic matter and nutrients fed a rich plankton community that supported prawn and sardine fisheries in the nutrient-poor waters of the Mediterranean.

Irrespective of the well-documented benefits and problems upstream, construction of the Aswan High Dam has been an unmitigated disaster for the complex estuarine system of the Nile Delta and the fishers of the Mediterranean coast. The Aswan High Dam traps most of the nutrient-rich silt that once replenished the floodplain and delta. The immediate ecological impact of the activation of the dam in 1965 was a sudden collapse of the sardine and prawn fisheries in the vicinity of the Nile Delta, from tens of thousands of tonnes each year to a mere few hundred. In recent years, the sardine fishery has increased to levels approaching those before the dam was built. This may represent an early response to increased nutrient outflow from urban and agricultural growth. Another effect of the dam's construction has been rapid erosion of the fertile Nile Delta along the Mediterranean coast where agriculture, fishing and aquaculture account for much of Egypt's food supply. This is largely as a result of trapped sediment in Lake Nasser upstream of the Aswan High Dam. The problem is compounded by deposition of sediment in the extensive network of irrigation and drainage canals on the delta itself.

The Nile Delta



Increases in cropping intensities and perennial irrigation combined with poor drainage of irrigated lands on the floodplain and delta have led to waterlogging and increased salinity. Inflow of relatively silt-free water and use of fertilisers have led to recent epidemic growth of weeds in waterway channels. In addition, by the time the sediments come to rest in the fields and lagoons, they are laden with municipal, industrial and agricultural waste from a region that is home to more than 40 million people.

Managing tourism: A mixed blessing for Benoa Bay, Bali

Bali, the focal point of Indonesian tourism, suffers many impacts from an industry commonly viewed as its economic saviour. To a point, tourism protects social and environmental values. After all, there is an incentive to take care of what people come to enjoy. However, Bali provides an example of how rampant tourist development can be environmentally and culturally destructive.

Tourism in Bali grew exponentially from the early 1970s, with foreign visitor numbers increasing from around 34,000 in 1971 to some 1.3 million in 1997. The enormous scale and pace of this development, and its uncontrolled nature, have had numerous negative social and environmental impacts. The Benoa Bay estuary, on Bali's southern peninsula, can be seen as a microcosm of tourism and coastal development issues in Indonesia.

Benoa Bay is a tidal estuary, enclosed on the ocean side by the Benoa Peninsula in the south and Serangan Island in the north, as well as an offshore coral reef system. The resort enclave of Nusa Dua lies along the coast to the south. The estuary has been affected by a number of human activities. It has suffered pollution from the rivers draining Bali's agricultural heartland and the heavily populated urban centre of Denpasar. Leachate from landfills and illegal dumping sites, and the dumping of garbage and untreated sewage into tidal creeks, are major problems. The Benoa Port facility and causeway, on reclaimed land in the middle of the estuary, have reduced natural flushing. Development and land reclamation have led to the loss of some 50 percent of the bay's mangroves since 1980. The Nusa Dua sewage treatment facility, for instance, is located in the southwestern mangroves of the estuary – away from the tourist activities on the sea coast.

Two tourism mega-projects, the Bali Turtle Island (Serangan) Development and the Bali Benoa Marina, were approved for the bay in the mid 1990s. These projects, with condominiums, golf courses, a cruise ship terminal, marinas and hotels, were to be developed on reclaimed land using locally dredged spoil. Material dredged from the estuary was to be used to reclaim approximately 1000 ha (25% of the area) of the bay and shallows outside Serangan Island, including turtle-nesting beaches. Both projects were halted by the 1998 Asian financial crisis after initial reclamation works had been completed. These included constructing a one-kilometre causeway from Serangan Island to the mainland and reclaiming large areas around the island.

Substantial loss of habitats has occurred in the dredged area of the estuary, and the once sandy beaches along the east coast of Serangan have been turned into a muddy mess, with little likelihood of remediation in the near future. Alongside many other human activities, uncontrolled tourism developments clearly contribute to the malaise of the coastal environment.

Key lesson:

- *Don't destroy what you came to enjoy.*

Managing mining runoff: Poisoned – Ok Tedi and Fly rivers, Papua New Guinea

At the outset one should also note that the Risk Assessment confirms the widely acknowledged view that the environmental impacts of mine operation are significant, and have been far greater than initially anticipated. The report also confirms the understanding that the impacts are likely to worsen, and will continue for some time even after the mine has closed and that the existing and potential future environmental impacts of the mining operation are directly related to the discharge of tailings and waste rock from the mine.

World Bank letter to the Prime Minister of PNG, January 2000

Key lesson:

- *The rights of local and Indigenous people must be protected in the pursuit of global commercial opportunities for profit.*

The operations of the Ok Tedi copper-gold mine in Papua New Guinea have been an environmental disaster for the Ok Tedi and Fly River systems. In this case Ok Tedi Mining Limited (OTML) intentionally dumped mine waste into the Ok Tedi and Fly rivers. A tailings dam, built under the project's original design, was destroyed in a landslide in 1984 and never rebuilt. Instead, the PNG government allowed OTML to discharge waste rock and mine tailings, containing copper and other heavy metals, directly into the river systems at a rate of around 65 million tonnes per year between 1984 and 1998. These sediments clogged the Ok Tedi and Middle Fly rivers, damaging fisheries and increasing the incidence and severity of flooding in the affected areas. Mine tailings and waste rock were swept into surrounding rainforest, swamps, creeks and village vegetable gardens, killing floodplain vegetation and threatening the livelihoods of villagers who derive their income from fish and garden crops. OTML admitted in internal reports that upper Ok Tedi fish stocks had declined between 50 percent and 80 percent and that mine wastes have spread down 1000 km of the Ok Tedi and Fly rivers and across more than 100 km^2 of land adjoining the river.

Rainforest killed by waste from the Ok Tedi mine (Photograph: Mineral Policy Institute)

Following legal action against BHP in the Victorian Supreme Court, the company reached an out-of-court settlement with a group of 30,000 Indigenous landholders. The settlement included a binding agreement to construct appropriate tailings containment facilities and instigate a dredging program to remove sludge downstream. In 2000, landowners launched new legal action against BHP, claiming the company had failed to meet the environmental obligations contained in the 1996 settlement. BHP effectively washed its hands of the problem in 2002, transferring its 52 percent share in OTML to a trust on behalf of the PNG government.

Managing mining run-off: The poisoning of the Tisza and Danube rivers, Europe

If environmental protection is the primary concern, then instead of legal proceedings to punish and compensate after an accident, it is far preferable to have strong and effective environmental protection laws to ensure accidents do not happen.

Sydney Morning Herald editorial, 16/02/00

In February 2000, a storage pond at a gold mine near the city of Baia Mare in northern Romania, swollen by heavy rains and melting snow, burst its banks releasing around 100,000 m^3 of water, containing an estimated 100 tonnes of cyanide, into small local rivers and ultimately into the River Tisza in nearby Hungary. Romania's River Somes, Hungary's River Tisza and Yugoslavia's Danube, Europe's largest waterway, were all affected. The spill wiped out most life within the Tisza for several hundred kilometres. Although the cyanide gradually lost its lethal effect as it became diluted with river water, hundreds of dead and dying fish piled up at the junction of the Danube and Tisza, just 50 kilometres upstream from the Yugoslav capital of Belgrade. Several hundred tonnes of dead fish were removed from the rivers. The Hungarian Government officially declared the Tisza a dead river. Hungarian towns along the Tisza banned the use of water, fishing and sales of fish and emergency water supplies had to be brought in for those living close by. The pollution disrupted the whole ecosystem of the Tisza, which is expected to take at least five years to recover. Two years later, water quality is back to normal, but fishermen have noticed a dramatic drop in the numbers of fish such as pike, perch and sturgeon. The poisoning has sparked a bitter dispute over compensation claims. The Australian-owned mining company, Esmeralda Exploration, which owned half the Romanian gold mine at Baia Mare, strongly denied responsibility and says the claimed extent of the damage was exaggerated.

Key lesson:

- *Causing environmental harm is not good for business! It's criminal.*

Managing invasive species: Zebra mussels in the Great Lakes, North America

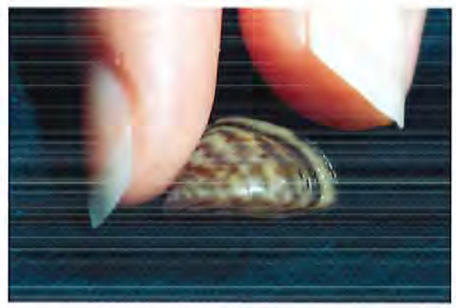
Key lessons:

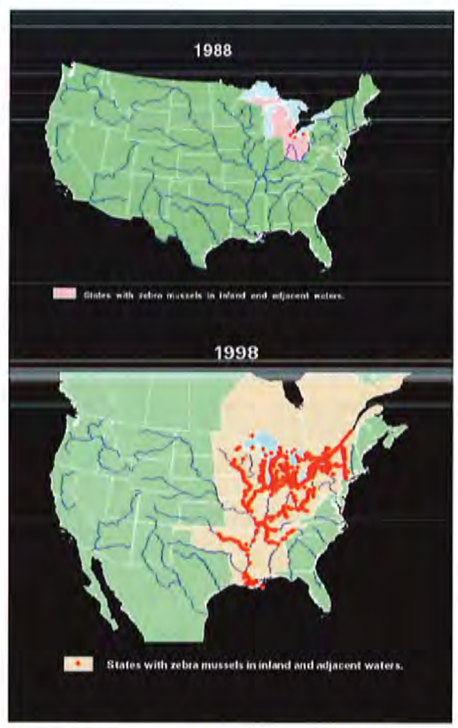
- *Prevention is better than cure. A cure is not always available.*
- *Local issues can become global problems.*

Zebra mussels encrust a vector averaging current metre deployed by the Great Lakes Environmental Research Laboratory

The movement of aquatic species from port to port via boat hulls and ballast water discharge is a global problem. The discovery of black-striped mussels in three marinas in Darwin Harbour in late 1998 highlighted Australia's vulnerability to outbreaks of exotic species. The incident, which elicited an immediate and full-scale response aimed at eradicating the offending mollusc, brought to mind the damage caused by another mussel in the Great Lakes region of North America. A relative of the black-striped mussel, the zebra mussel, has an economic impact of about US$600 million each year in the Great Lakes region. Most of this cost is in remedial engineering, and cleaning pipes and water systems that are encrusted with the mussels. Zebra mussels were transported from Europe as stowaways in ship ballast water. The mussels restrict flow through intake pipes, disrupting supplies of drinking, cooling, processing and irrigating water. They attach to boat hulls, docks, navigation aids, breakwaters and locks, increasing maintenance costs. Zebra mussels rapidly colonise water intakes, forming layers up to 200 mm thick. They alter freshwater ecosystems.

In Darwin, all ships that had been in the area where the mussel had invaded were traced and examined. Any mussels on them were destroyed. This large task involved about 400 vessels. Areas where the mussel had invaded were quarantined and treated with chlorine and copper sulfate. While the drastic steps taken to eradicate the mussel from its invasion sites also caused some local environmental damage, this was considered well worth the risk. If the mussel survives, even just a few of them, the consequences for Australia could be catastrophic.





Zebra mussel from Lake Huron, 1992 (top);

Ten years of zebra mussel spread throughout north American waterways (bottom)

Managing irrigation: The Río Colorado Delta, Mexico

On the map the Delta was bisected by the river, but in fact the river was nowhere and everywhere, for he could not decide which of a hundred green lagoons offered the most pleasant and least speedy path to the Gulf. So he travelled them all, and so did we. He divided and rejoined, he twisted and turned, he meandered in awesome jungles, he all but ran in circles, he dallied with lovely groves, he got lost and was glad of it, and so were we.

Aldo Leopold

Key lesson:

- *Water is life!*

In 1922, the year Aldo Leopold penned these thoughts while canoeing through the Colorado Delta, then-US Secretary of Commerce Herbert Hoover allocated 90 percent of the Colorado's flow to the seven states along the river. Mexico, where the river flowed to the delta and the Sea of Cortez, would get what remained.

Over the next 40 years a series of mega-dams was built on the river, which together with the All American Canal that diverts water for irrigation, saw Hoover's plan realised. The Río Colorado Delta, more than 7500 km^2, and possibly the richest and most diverse wetland system in western North America, was starved of water.

This estuary was a vast system of wetlands, home to more than 400 species of plants and animals including the vaquita porpoise, the smallest member of the dolphin family. The vaquita is now listed as critically endangered, with the remaining animals (estimated at less than 200) threatened by the pressures of fishing and habitat loss. Many other species have become endangered or extinct. The idea of allowing water to be 'wasted' by flowing to the sea (or to Mexico) is clearly an anathema to water users in the US southwest who have yet to come to terms with the fact that they live in a desert. Even so, domestic water use pales compared with that of agribusiness. Nearly 80 percent of the Colorado's flow goes to corporate farming, much of it to low-valued crops needing lots of water. And their political clout means big agribusiness pays a tiny fraction of the price paid by city residents. The 'use it or lose it' attitude is typified by the Glen Canyon Dam, which holds back two years of flow for the entire river in what was one of the world's most spectacular canyons. This dam was built to regulate downstream flow and provide hydroelectricity. Perversely, around 6 to10 percent of the river's flow is lost through evaporation and seepage from Lake Powell above the dam. Just before the Colorado crosses the US/Mexico border 75 percent of its flow is diverted to the All American Canal. From there water is flushed into wasteful flood-irrigation systems before eventually trickling down into the Salton Sea. This vast salt lake was created by accident in 1905. Ironically, the decline of the Colorado Delta has seen the Salton Sea grow in importance as migratory bird habitat. On the Mexican side of the border, the 10 percent flow that was finally guaranteed in 1944 is sucked dry by Mexican farmers and most of the once lush delta is now bare mud and saltflats.

The Rio Colorado Delta

Managing overfishing: Fisheries decline in the Indus River delta, Pakistan

Key lessons:

- *Fisheries and other biological resources are sustainable only when used wisely.*

Mouths of the Indus River

Overfishing and pollution are a threat to the productive fisheries of the Indus Delta in Pakistan and the livelihood of thousands of fishermen. The Indus Delta mangrove ecosystem extends over about 600,000 ha on the Sindh coast, between Karachi and the southwestern border of India – the largest area of arid mangroves in the world. The fan-shaped delta is built up by vast deposits of silt washed down from the Karakorams and the Himalayas by the river Indus. The delta consists of 17 major creeks and extensive mudflats, sand dunes, saltmarshes and mangroves. The vast mangrove forests are ideal habitat and nursery for numerous fish and prawn species. Many of these spend part of their lifecycle in the delta, before returning to sea where they grow to marketable size.

An estimated 135,000 people depend on this ecosystem, predominantly for fish. The marine fishing fleet of Sindh operates around the edge of the delta, while thousands of fish live within the network of mangrove-fringed creeks and tidal channels of the delta itself. The Indus Delta fishery is being increasingly degraded. Contributing factors are non-judicious fishing techniques, reduction in freshwater flow, pollution and changes in hydrography, degeneration of mangrove habitat and massive amounts of untreated industrial and municipal wastes discharged into the Indus. Various fish and prawn species including black tiger prawn (*Penaeus monodon*) and dangri (barramundi) are now rare in the southwestern delta near Karachi.

Illegal small-mesh netting in the creeks and channels of the delta contributes to the fisheries decline. These nets, known locally as *Bhola*, *Katra* and *Gujjo*, are used for catching juvenile prawns and sub-adult fish from areas considered to be nursery grounds for many species. Most of the fish caught, including juveniles that could potentially grow to over a metre, are of no value other than as fishmeal for animal feeds. The Sindh Fisheries Ordinance of 1980 banned the use of small mesh nets and catching prawns during the breeding season, but neither regulation has been adequately enforced to slow the decline of the fisheries.

These overseas case studies show how seriously misunderstanding and bad treatment of estuaries can affect people and other species. Compared with the examples, most of our estuaries are still relatively healthy. But we cannot be complacent about our record. Australians have already made some world-class blunders in estuary management, both here and overseas. To prevent further mistakes we need good research, conscientious management, commitment to sustainability from all estuary users and a motivated and well-informed public.

Moving forward...
...with our heads, hearts and hands

Australia has more than a thousand estuaries, each a dynamic and unique system. Almost every one of them has decisions on resource use made about it every day. Many of the issues featured in case studies in this and preceding chapters are symptomatic of an increasing population with a diminished connection and understanding of the natural environment on which we all depend.

Ensuring healthy productive estuaries for the future will need a collaborative partnership among governments, business, community and individuals using our heads, our hearts and our hands.

Using our heads: knowledge and awareness

We need to understand how estuaries function and appreciate that they are constantly changing. As Australians, we all want to live on the coast and if we can't live there we like to holiday there. Buffer zones play an important role in effective estuary management providing estuaries with the freedom to change and move.

Protective management arrangements

Estuary restoration is expensive and in many cases not possible. Protective management is recognised to be more cost-effective in the long-term. The concentration of near-pristine estuaries in northern tropical Australia and western temperate Tasmania, shows that the different types of estuaries found in populated parts of Australia are not well represented in the near-pristine list. The protection of a representative group of near-pristine estuaries from around Australia, selected on the basis of estuary type, size, and location would provide a framework for improved nature conservation. These protected estuaries would also give us the basis for comparison we will need for the best management of all our estuaries.

Trawlers on the Clarence River at Yamba

Land use

We need to manage our lands with our coasts and estuaries in mind. This means continual improvement of our land use patterns and practices, with attention to soil erosion, nutrient balance, dryland salinity, vegetation and pasture management, water resource sustainability and water use efficiency.

Mangrove restoration in progress

Institutional and policy needs

We need a balance between public and private benefits and costs, especially for the key public resources provided by our rivers and estuaries (such as water). More integrated approaches to natural resource management are needed.

Often we fail to manage estuaries well because many institutions are involved but no-one is in charge. Lead agency responsibilities must be clearly defined at state and national level. An Australia-wide initiative in estuary protection and management would provide a much needed policy framework for states to start protective management through their various agencies and existing laws.

At a state and regional level, catchment management processes need to formally recognise and incorporate targets for managing estuaries.

Information provision

Data collection, monitoring and assessment must be cost-effective. The information gathered must support management decisions and track progress in management programs. Community groups are key to effective estuary management. They have the local commitment and passion to get the job done but need better access to information and resources.

Research needs

The Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management, with state and territory agencies and other researchers, will continue to provide information and tools to support more effective estuary management decisions.

Strategic research priorities vary for differing estuary types. Certainly we need to develop better understanding of the:

- advantages and disadvantages of artificially opening coastal lakes and lagoons to provide better advice for entrance opening strategies
- importance of the timing and quantities of freshwater flows and effects of change in environmental flows on estuarine ecology
- role of fringing mangroves and saltflats in macrotidal, tropical estuaries
- mechanisms for prevention and control of invasive species
- impacts of harmful algal blooms and eutrophication in coastal waters (including associated anoxic and hypoxic events)

- role of extreme climatic events in estuarine condition and predictions on the likely influence of climate change
- combined implications of multi-stressors, especially on fish populations
- effective protective management and rehabilitation strategies
- links between floodplain and estuary ecology particularly water quality and loss of fishery habitat
- impact of modified fish communities on estuary condition and ecological functioning

Using our hearts: attitudes and understanding

We manage and protect what we value. It is OK to care about estuaries! We often aren't as connected to estuaries as we are with the open coastline, freshwater streams and rainforests. This stems from a lack of appreciation of the intrinsic value of estuaries and how interesting they are. We need to protect public access and ensure we get out there and connect with our estuaries. We each have a personal responsibility to gain the skills we need as individuals, professionals or community leaders to read and understand our environment, including estuaries.

Education and awareness

Estuaries are important to, and valued by, Australians. Educational institutions and community groups, such as Waterwatch and Seagrass Watch, provide information on Australia's estuaries and their management. Continued efforts in communication will build understanding. From understanding will follow improved management and healthier estuaries.

Using our hands: skills and behaviour

In many cases there is still time to turn things around for our estuaries. Many systems are still in good condition and enjoyed by people but obviously heading in the wrong direction. It is up to all of us to play our part in reversing the decline.

Monitoring and assessment

Estuaries are dynamic systems with variable response times. We need to understand the time it can take for changes to make improvements in estuary condition. Significant information gaps exist in relation to Australia's estuaries. We need:

- enhanced integrated assessment and monitoring activity
- improved reporting of existing activities undertaken by all levels of government and the community

Glenelg River, Nelson, Victoria

- agreed reporting frameworks so information collected at the local level can be used in processes like State of the Environment reporting
- increased use of online data warehousing to improve access to and value adding of local, state and Commonwealth information
- use of new technology to capture nationally comprehensive data and information (e.g. the use of remotely-sensed imagery to monitor turbidity)
- detailed studies of representative estuaries chosen by type, location, size, condition and process type, with outcomes applied to similar systems

Community volunteers remove gross pollution from a misused waterway

- community involvement (e.g. Waterwatch, Coastcare, Fisheries Action Program) to get estuary information on physical aspects (such as depth), habitat type and status, make up and status of fisheries, opening and closing frequency and for ground-truthing remotely-sensed information
- assessment and management frameworks to better account for spatial and temporal variation in an estuary
- assessing and monitoring fish communities to gain a better appreciation of populations, changes and priorities for estuary protection and rehabilitation to sustain fisheries
- data presented within appropriate natural resource management frameworks (e.g. population census data by catchment boundaries)
- ongoing attention to selection, evaluation and refinement of attributes for assessing the condition of Australian estuaries and collection of minimum data sets
- monitoring and assessment activities need a close partnership between land and waterway managers, policy-makers, the interested community and scientific specialists

Only about 50 of Australia's estuaries have been studied in detail. This has generally been because they are near population centres, have particular problems or a decline in their condition, which has sparked an interest in them. A more integrated monitoring program would be of benefit if based on estuary type, location, condition, beneficial uses and size.

It is unlikely that there will ever be enough resources to monitor all of Australia's estuaries in detail. Even if estuaries were to receive this level of monitoring, better value for money would be investment in intervention strategies to improve and protect estuarine condition. A more cost-effective approach may be to select a small number of representative estuaries from around Australia and investigate their behaviour and management needs in detail, then adapt this understanding for other similar systems.

Management and action

Australians are interested in the health of their estuaries and expect them to be well managed. Key management needs to improve the condition of Australian estuaries include:

- undertaking habitat restoration to rehabilitate damaged estuaries
- maximising habitat and catchment protection to prevent the degradation of less modified estuaries
- minimising run-off of nutrients and other pollution from urban areas and agricultural catchments. This can be done by improving land use management. Tertiary treatment and land application of sewage effluent, stormwater retention basins and the re-establishment of filter strips, riparian forests and wetlands to trap overland flow of pollutants are other important measures
- implementing catchment management strategies to target and intercept increased sediment loads being delivered to estuaries
- control and reduce the likelihood of infestation by invasive (pest) species
- ensuring the recognition of the economic and non-market values of estuaries, factoring their net worth for aquaculture, recreation, nature conservation and commercial fisheries into planning decisions such as urban development and infrastructure
- developing multiple objective strategies for the management of estuary entrances
- restoring tidal flushing, particularly to tide-dominated systems, by minimising interference to flows from causeways, bund walls, culverts, floodgates and bridge approaches coupled with strategic dredging to re-establish tidal channels

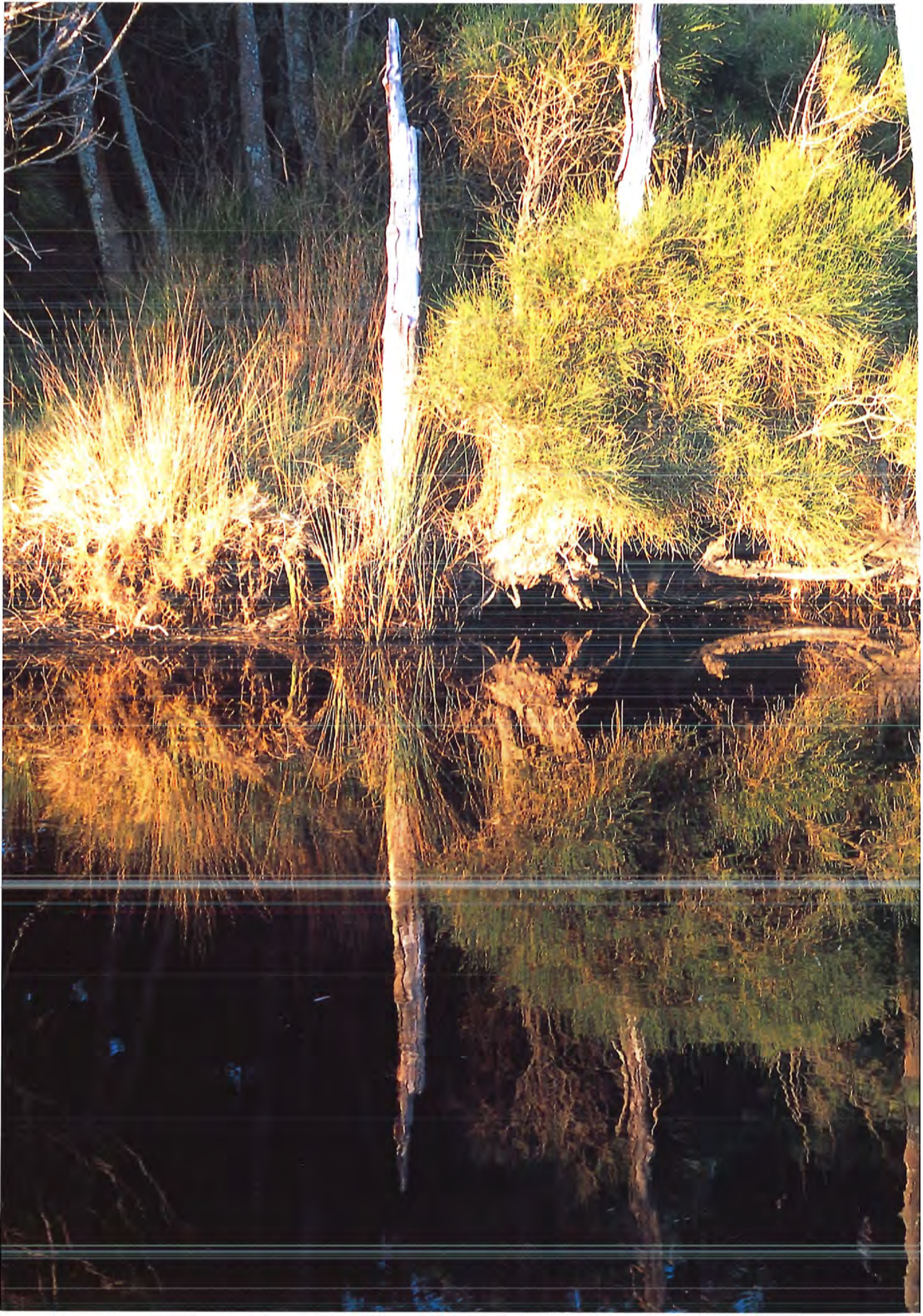
Hands-on estuary management – restoring mangroves (below)

*This purple crab (*Metapagrapsis *sp.) lives only in healthy mangroves (bottom)*

We are all estuary managers

When we talk about estuary management we are really talking about managing our own activities and impacts. Each one of us has a role to play in estuary management. We hope that this book has helped you build the confidence you need to use your head, your heart and your hands to improve the condition of your estuary.

So get out there, enjoy what your local estuaries have to offer, take care of them, talk to others and get involved!



Estuary resources

Estuary contacts around Australia

National estuary contacts

Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management (Coastal CRC)

The Coastal CRC is a research organisation providing decision-tools, understanding and knowledge for the effective management and ecosystem health of coastal zones, estuaries and waterways

Coastal CRC

Coastal Centre, 80 Meiers Road,
Indooroopilly, Qld 4068

ph 07 3362 9399
fax 07 3362 9372

www.coastal.crc.org.au

Fisheries Research and Development Corporation (FRDC)

The Fisheries Research and Development Corporation (FRDC) is a rural research and development corporation within the Australian Government portfolio of Agriculture, Fisheries and Forestry. It is responsible to its stakeholders for identifying fisheries research and development needs and the means of addressing them through a planning process and by contracting with research providers.

Fisheries Research and Development Corporation

Fisheries Research House, 25 Geils Crt,
Deakin, ACT 2600
ph 02 6285 0400
fax 02 6285 4421

PO Box 222,
Deakin West, ACT 2600

www.frdc.com.au

National Estuaries Network (NEN)

The NEN, managed by the Coastal CRC is a technical forum for state and territory estuary managers. Estuary scientists also participate in the NEN. Contact NEN through the Coastal CRC (see above).

National Land and Water Resources Audit (NLWRA)

The NLWRA provides data, information and nationwide assessments of Australia's land, water and biological resources to support sustainable development.

National Land and Water Resources Audit

Level 2, UNISYS Building,
91 Northbourne Ave,
Turner, ACT 2612
ph 02 6257 9516
fax 02 6257 9518

GPO Box 2182,
Canberra, ACT 2601

www.nlwra.gov.au

OzEstuaries

OzEstuaries is an interactive database with information about 974 Australian estuaries. It includes conceptual diagrams of estuary function and information about indicators of estuary health.

Geoscience Australia

Cnr Jerrabomberra Ave & Hindmarsh Drive,
Symonston, ACT 2609
ph 02 6249 9650
fax 02 6249 9956

GPO Box 2182,
Canberra, ACT 2601

www.ozestuaries.org.au

State estuary contacts

New South Wales

New South Wales Department of Infrastructure Planning and Natural Resources

23-33 Bridge St, (Natural Resource Management)
Sydney, NSW 2000 (near Circular Quay)

PO Box 39,
Sydney, NSW 2001

ph 02 9228 6111 (switch)
fax 02 9228 6455

www.dlwc.nsw.gov.au

Victoria

Environmental Protection Authority, Victoria

40 City Road,
Southbank, Vic 3006

ph 03 9695 2722
fax 03 9695 2785

www.epa.vic.gov.au

Tasmania

Department of Primary Industries, Water and Environment

1 Franklin Wharf,
Hobart, Tas 7001

ph 03 6233 8011
fax 03 6234 1335

GPO Box 44,
Hobart, Tas 7001

www.dpiwe.tas.gov.au

South Australia

Environment Protection Authority, South Australia

Level 5, 77 Grenfell Street,
Adelaide, SA 5000

GPO Box 2607,
Adelaide, SA 5001

ph 08 8204 2004

www.epa.sa.gov.au

State estuary contacts ctd.

Western Australia

Water and Rivers Commission, Western Australia

Level 2, 3 Plain Street,
East Perth, WA 6004
ph 08 9278 0300
fax 08 9278 0301
www.wrc.wa.gov.au

PO Box 6740 Hay Street,
East Perth
WA 6892

Northern Territory

Department of Infrastructure Planning and Environment

Energy House, 20 Cavenagh Street,
Darwin City, NT 0800
ph 08 8999 3662 (Natural Resources Division)
fax 08 8999 4403
www.lpe.nt.gov.au

Queensland

Environmental Protection Agency Queensland

160 Ann Street,
Brisbane, Qld 4000
ph 07 3227 7111 (Central Office switch))
www.epa.qld.gov.au

PO Box 155,
Brisbane Albert Street
Qld 4002

Conceptual diagram resource

Integration and Application Network (IAN)

The Integration and Application Network supports a free, web-based symbol library and conceptual diagram tutorials so researchers, resource managers and students can produce the type of conceptual diagrams used extensively in this book. The Integration and Application Network is a faculty initiative of the University of Maryland Centre for Environmental Science

Integration and Application Network
University of Maryland Centre for Environmental Science
PO Box 775,
Cambridge, MD 21613 USA
ph +1 410 221 8457
fax +1 410 228 3243
www.ian.umces.edu

Glossary

Abstraction	permanent removal of water from a stream or channel
Acid sulfate soils	soils which can leach sulfuric acid when physically distrurbed
Algal bloom	the multiplication of one or more species of microscopic water plants to high densities under certain environmental conditions
Alluvial	relating to material deposited by running water
Anaerobic	environmental conditions where oxygen is not available
Anoxic	lacking oxygen
Aquifer	an underground water-bearing layer of porous rock in which water can be stored
Benthic	of the bottom or bed of a water body
Bioassays	examination to identify and quantify which life forms are present
Bioavailability	the ease with which a chemical is absorbed into plants and animals
Biodiversity	the variety of all life forms, the genes they contain and the eco-systems they form
Biota	refers to all plant and animal life in an area
Biotic	of plant or animal life
Brackish	somewhat briny or salty
Catchment	an area drained by a stream or a stream system
Chlorophyll *a*	plant photosynthetic pigment (used as a measure of algal concentrations in water)
Crustaceans	aquatic animals with a hard external skeleton and jointed appendages. Includes crabs, lobsters, prawns etc. but also barnacles
Cyanobacteria	microscopic, photosynthetic aquatic organisms, commonly referred to as blue-green algae
Detritus	fallen organic material such as leaves or twigs
Dieldrin	a synthetic insecticide regarded as a major and serious pollutant (banned in US in 1974)
Dinoflagellates	microscopic, (usually) one-celled, flagellated, often photosynthetic, commonly regarded as 'algae'
Ecosystem	a community of life forms interacting with one another; may include humans
Endemic	species that is unique or confined to a specified locality

Eutrophication	a process whereby nutrients, especially nitrogen and phosporus become over-abundant in a waterbody, often leading to the proliferation of algae
Fluvial	relating to or occuring in a river
Floodplain	the flat area, usually toward the lower end of a river, where periodic flooding has deposited river-borne materials
Geomorphology	science of describing and interpreting landform and the processes of landscape formation
Hypersaline	salinity well in excess of that of sea water; found in enclosed water bodies and derived from land salts
Hypoxic	deficient in oxygen
In situ	in the natural habitat as opposed to in a laboratory etc.
Isotope	an alternate form of an element having the usual number of protons but a non-standard number of neutrons; the fewer or additional neutrons give the isotope a different atomic weight to the regular element and may make the isotope radioactive. Isotopes (such as radioactive carbon) are used as tracers in biological systems or processes.
Macroinvertebrates	animals without backbones, easily seen without magnification
Nitrification	conversion of nitrogenous matter into nitrates by bacteria
Pelagic	marine life living or occurring in the upper waters of the open sea
Phytoplankton	microscopic plants and cyanobacteria that live free-floating in an aquatic environment
Secchi depth	a measure of the clarity, or turbidity of water
Slumping	slipping of earth or rock
Stromatolite	laminated structures built from layers of microorganisms such as bacteria or algae. Most stromatolites are fossils. Rare modern ones, still developing from living organisms, occur in hypersaline lagoons in warm climates such as those in Shark Bay, Western Australia.

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of estuaries as we know them today began at the end of the last ice age, ears ago, after a period of climate change. We are again facing an era of ainty. It is now widely accepted that human activity on the planet is a f the current phase of global warming and climate instability. Climate one of the challenges facing us as managers and custodians of Australia's ry Australian has a role to play in maintaining our estuaries as healthy vironments for benefit and enjoyment of present and future generations.

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ISBN 0-9578678-8-3

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