Waterwatch Estuary Guide

A guide to community monitoring of water quality and estuary health

waterwatch NEW SOUTH WALES
Communities Caring for Catchments

NSW GOVERNMENT | Environment, Climate Change & Water

Australian Government

Acknowledgements

This *Waterwatch Estuary Guide* and the accompanying *Waterwatch Estuary Field Manual*, have been developed by Waterwatch coordinators for Waterwatch groups in coastal areas of New South Wales. The methods and procedures have been adapted and enhanced to ensure the success of monitoring within estuaries.

Many thanks to the following people for contributing their resources and expertise:

- Ingrid Berthold, Hunter Central Rivers CMA Waterwatch Coordinator
- Luke Brown, Bournda Environmental Education Centre.
- Amanda Gregory, Department of Education and Training and Hunter–Central Rivers CMA Waterwatch Education Officer
- Colin Mondy for sharing his extensive expertise as Waterwatch Coordinator (retired)
- Beryl Newman, Department of Environment, Climate Change and Water, Waterwatch Coordinator
- Carla Sbrocchi, Waterwatch Catchment Officer, Northern Rivers CMA
- Jane Smith, Community Environment Network, Ourimbah
- Debbie Venter, Community Environment Network, Community Seagrass Monitoring Coordinator
- Samantha Willis, Community Environment Network, Ourimbah.

NSW Waterwatch gratefully acknowledges the permission granted to use materials from a variety of sources including:

- Waterwatch Australia Steering Committee for material from the *Waterwatch Australia national technical manual* modules
- Department of Land and Water Conservation, draft *NSW Estuary Monitoring Manual*
- Department of Natural Resources (WA), *Ribbons of Blue: in and out of the classroom*
- OzCoasts at www.ozcoasts.org.au for permission to use online resources
- NSW Department of Industry and Investment Fisheries for permission to use photographic material on mangroves, saltmarsh, seagrass and caulerpa
- Waterwatch South Australia, for use of some text and illustrations from estuary resources
- Mark Hacking, Edith Cowan University, investigation procedures and worksheets
- Hawkesbury–Nepean CMA for permission to use saltmarsh illustrations
- Lake Macquarie City Council, for assistance with seagrass wrack methodology
- The Office of the Lake Macquarie and Catchment Coordinator for graphics from the publication *Living on the Edge*

NSW Waterwatch acknowledges the support provided in the development of this valuable resource by the Waterwatch network across New South Wales and Australia, and the community involved in Waterwatch.

The *Waterwatch Estuary Guide* and *Waterwatch Estuary Field Manual* are published by:
Department of Environment, Climate Change and Water NSW
59–61 Goulburn Street, PO Box A290, Sydney South 1232
Ph: (02) 9995 5000 (switchboard)
Ph: 131 555 (environment information and publications requests)
Ph: 1300 361 967 (national parks, climate change and energy efficiency
information and publications requests)
Fax: (02) 9995 5999 TTY: (02) 9211 4723
Email: info@environment.nsw.gov.au Website: www.environment.nsw.gov.au
ISBN 978 1 74232 886 7, DECCW 2010/685

How to use this guide

This *Waterwatch Estuary Guide* and the *Waterwatch Estuary Field Manual* have been designed to accompany the Waterwatch guides and field manuals for monitoring freshwater waterways. The two estuary documents contain specific information and activities required for monitoring in estuaries. They have been designed to provide information and sampling techniques for all ages, as a guide to designing and implementing a Waterwatch estuary monitoring program within schools and the community.

The methods and procedures described combine best practice and scientific rigour with straightforward instructions, to ensure participants gain maximum benefit while also contributing high quality data to the Waterwatch database. Such data becomes a valuable tool for natural resource managers to use in catchment planning.

The guide is divided into numbered sections:

Section 1: Introducing Waterwatch and maintaining healthy estuaries

Section 2: Monitoring water quality in estuaries

Section 3: Introduction to estuarine habitats

Section 4: Saltwater bugs

Section 5: Human impacts on estuaries

Section 6: Glossary

Section 7: Bibliography

This guide is to be used in conjunction with the *Waterwatch Estuary Field Manual*, as well as the relevant *Waterwatch Freshwater Field Manual* and guide, and contains cross-references to those documents. For students, an additional resource providing estuary fact sheets and work sheets is available to complement the estuary field manual and guide.

Waterwatch offers a way for students and other interested community members to get involved in monitoring the health of their environment and to take part in managing some of the problems.

Congratulations on your involvement in Waterwatch!

Table of contents

SECTION 1

Introducing Waterwatch and maintaining healthy estuaries

Waterwatch is concerned with the health of catchments and waterways. Water quality, biodiversity and the health of the environment are all interconnected. Waterways link upstream ecosystems to downstream areas and both affect each other. In coastal regions, the health of the estuary will often have impacts well up into the catchment, but more importantly, estuary health affects human health.

This section introduces the Waterwatch program and provides important background information about estuaries.

1.1 Welcome to Waterwatch!

Waterwatch helps the community, including school students, understand water quality issues and how to manage them within catchments. This will help to create healthy waterways and promote the sustainable use of this precious and limited resource.

In Australia, climate change, drought and the pressure of population have all contributed to increasing pressure on our water resources. When waterways are degraded by natural or human factors, it not only reduces freshwater supplies, but it also affects aquatic ecosystems.

Waterwatch uses action learning methods and by adopting an investigative approach, community groups and students can become involved in natural resource management within their local environment. Waterwatch engages communities by:

- raising awareness
- capacity building
- collection of quality assured community data
- participation in collaborative action
- building networks and partnerships.

In Australia, 90% of the population lives on the coast and many people spend recreational time in or near estuaries. Estuaries dot the NSW coast, with a major lake or estuary every 100 km. The importance of many aspects of estuarine and marine habitats, including their environmental, economic and recreational values, earns them a place in the Waterwatch program.

An estuary monitoring program can be designed to:

- identify problems and hotspots
- develop benchmarks and assess future change
- identify and prioritise future management requirements
- measure the effectiveness of rehabilitation works
- monitor and evaluate management procedures
- enhance community understanding of estuarine issues
- provide education and training
- assess new management and catchment-use practices
- identify long-term trends in selected indicators
- assess the impact of modification works.

1.2 What is an estuary?

An estuary is a partly enclosed body of water where a river meets the sea. It is a transition zone, where freshwater from the land meets the ocean and mixes with saltwater.

Estuaries are constantly changing due to the movement of water in and out of the estuary with the tide. Estuaries are therefore dynamic places with many habitats where living things have to cope with changing salinity, temperature and often regular wetting and drying.

A wide range of habitats and aquatic ecosystems make up estuaries. When they are healthy and functioning well, estuaries are highly productive environments and a rich food source. Estuaries are often called 'fish nurseries' because they are a place where fish and other marine creatures come to spawn and grow.

Estuaries have been identified as one of the most productive ecosystems on Earth.

Types of estuaries

Estuaries come in all shapes and sizes and have many different names, such as bays, lakes, lagoons, harbours, rivers or inlets.

The main types of estuaries in New South Wales are drowned river valleys, barrier estuaries, saline coastal lakes and estuaries formed by rivers.

Drowned river valleys

These estuaries have the following characteristics:

- They have wide openings to the sea, deep channels and steep sides.
- There is a moderate tidal influence.
- Upstream from the mouth of the estuary, channels are narrow and the deposition of sediment causes extensive floodplains and tidal river channels.
- The salinity decreases gradually upstream, although king tides and flooding can cause large fluctuations in salinity at any particular location.
- These estuaries are very open to the sea and support habitats that are typically marine near the estuary mouth.

Examples of drowned river valleys include Hawkesbury–Nepean, Georges River, Clyde River and Port Hacking.

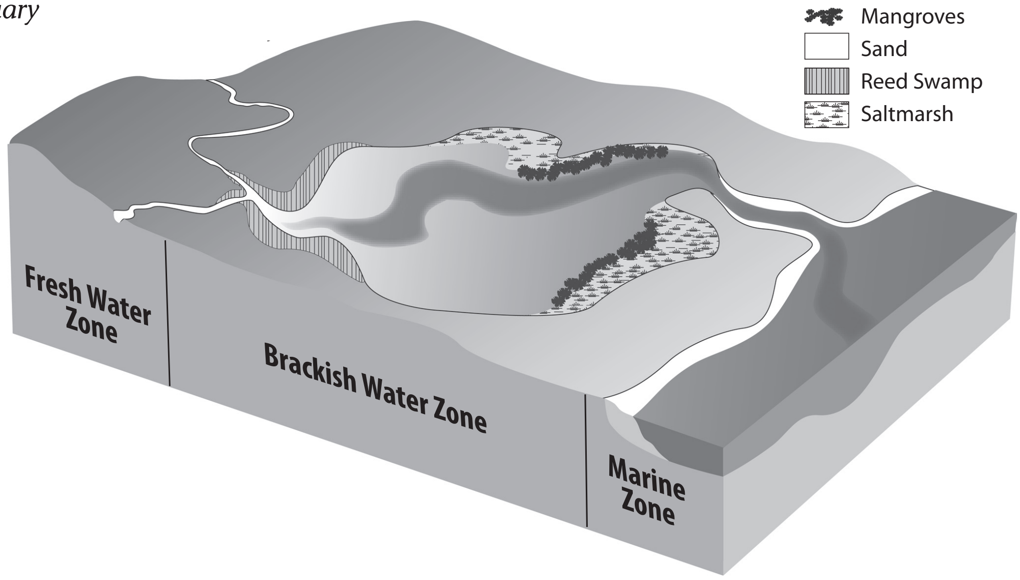
Barrier estuaries

Barrier estuaries are lagoons and lakes where the general shape has been formed by the influence of waves. These estuaries may have the following characteristics:

- Long narrow entrance channels or a barrier formation such as a sand bar limits the influence of tides.
- Where there is high river flow, the estuary is seldom cut off from the sea.
- Salinity levels rapidly increase from the mouth of the river into the ocean entrance.
- These estuaries are filled by the deposition of sediment from catchments.
- They support a diverse range of habitats, from marine, to brackish, subtidal and intertidal.

Barrier estuaries are common around the temperate coasts of Australia. Examples include the Clarence, Richmond and Hunter rivers. Young barrier estuaries are known as tidal lakes and are characterised by relatively small upper catchments. Examples of young barrier estuaries are Pambula Lake, Tuggerah Lakes, Narrabeen Lagoon and Lake Macquarie.

Barrier estuary



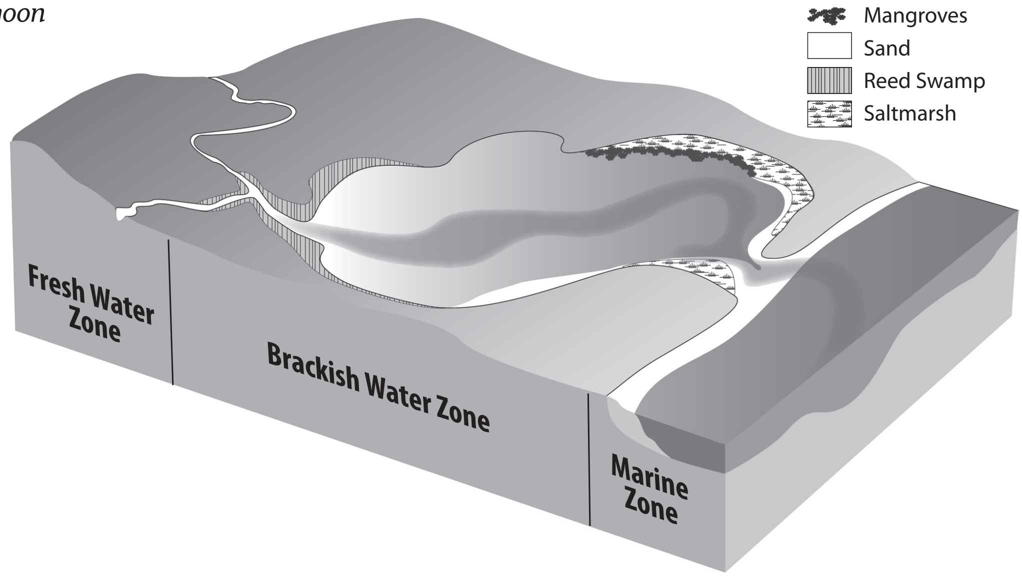
Saline coastal lakes

These lakes are also called intermittently closing and opening lakes and lagoons (ICOLLS). ICOLLS are immature wave-dominated estuaries and may have the following characteristics:

- They lack tidal influence and depend on wind currents to mix the freshwater and saltwater.
- Some coastal lakes are permanently opened by artificial channels.
- Other coastal lakes are artificially opened by mechanical means, usually when nearby properties or roads are under threat of flooding.
- Artificial opening can often be detrimental to the health of the estuary and there are policies in place to govern this activity.

Examples of saline coastal lakes include small systems such as Dee Why and Manly lagoons, but can include larger systems such as Wollumboola Lake and Wallaga Lake.

Coastal lagoon



Estuaries formed by rivers

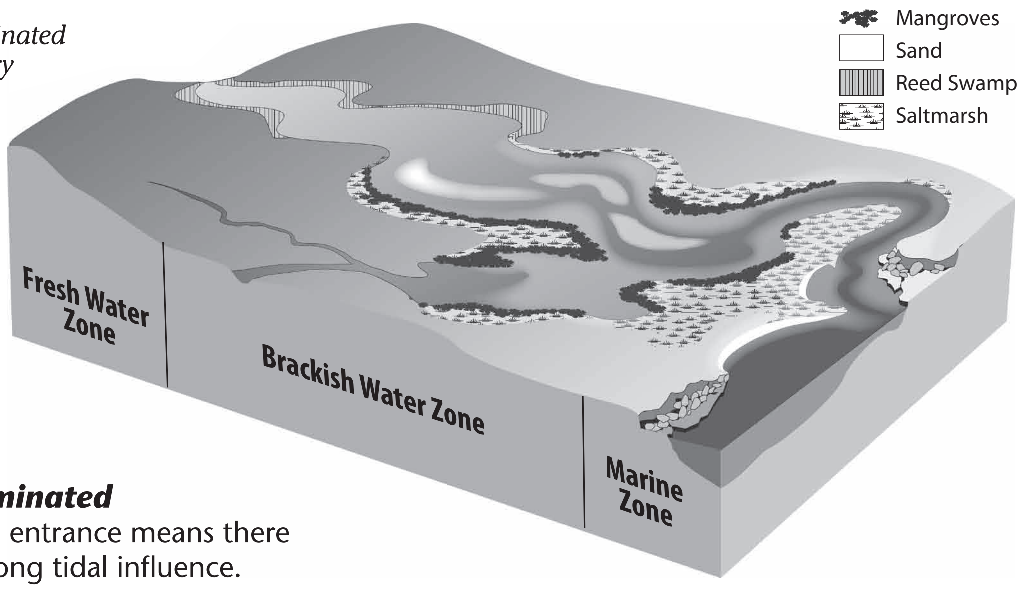
There are two types of estuaries formed by rivers: wave dominated and tide dominated.

Wave dominated

- River deltas can be influenced by landform features such as sand bars, or other barriers built by waves.
- Behind the barrier, the landscape is shaped by the river.
- There is limited tidal influence.
- Salinity depends on the amount of mixing due mainly to wind.
- Salinities can vary from well-mixed to stratified, or layered.
- Stratification occurs when freshwater lies over the top of the heavier, denser saltwater.

Most estuaries in south-east Australia are wave dominated; Wagonga Inlet, Narooma, is an example.

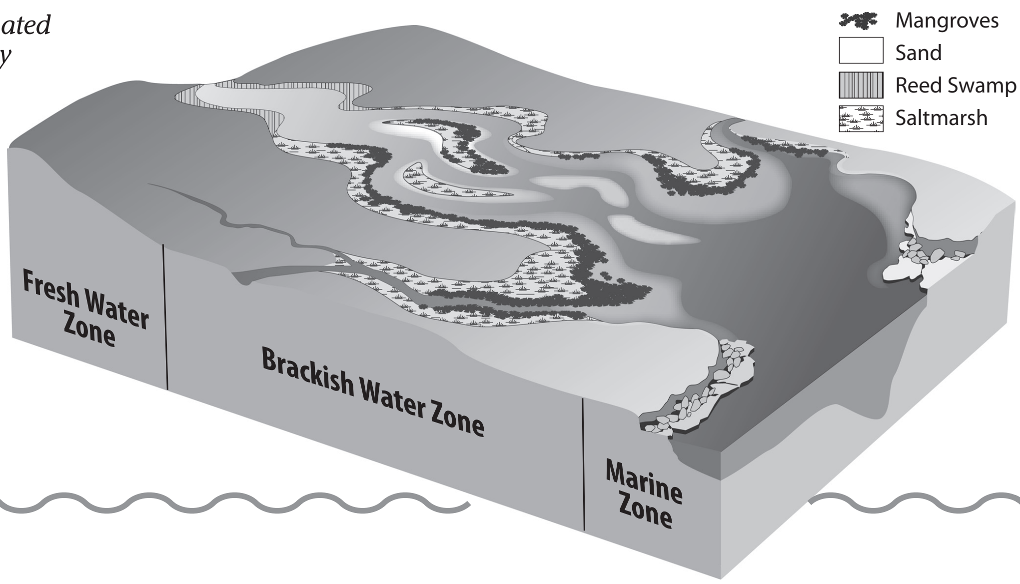
Wave dominated river estuary



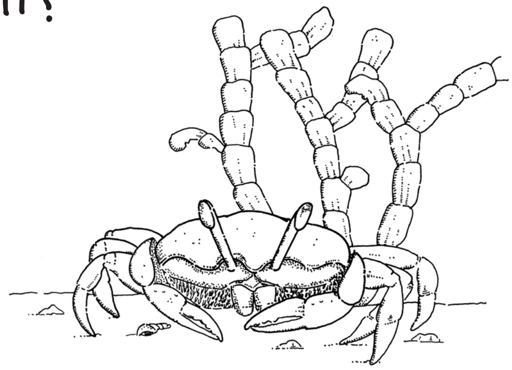
Tide dominated

- A large entrance means there is a strong tidal influence.
- There is strong mixing of freshwater and saltwater.
- There are a variety of habitats found in this type of estuary, including mangroves, saltmarsh, intertidal flats, rocky reefs and rocky shores.
- Freshwater wetlands can also occur in this type of estuary due to aquatic plants that trap sediment (and pollutants), holding back the marine influence.
- Salinity in these estuaries increases with closeness to the sea.

Tide dominated river estuary



1.3 Why are estuaries important?



Biodiversity

Estuaries support a diversity of wildlife, including shore birds, fish, prawns, crabs, oysters and other shellfish, marine worms, marine mammals and reptiles. These animals are linked to one another through complex food webs. Many fish species and crustaceans spend their early life stages in the protected, nutrient-rich waters of estuaries. Birds such as the white bellied sea eagle, the pelican and silver gull also visit these areas to nest and feed.

Estuaries reduce pollution

Estuaries are important filters. Water from catchments carries sediment, nutrients and other pollutants that can be filtered by plants within the estuary. This creates cleaner water, which benefits both people and marine life.

Estuaries reduce the impacts of floods and storms

Wetland plants and soils also act as a natural buffer between the land and ocean, absorbing flood waters and reducing the impacts of storm surges. This protects land-based organisms. Saltmarsh grasses, seagrasses, mangroves and other estuarine plants also help prevent erosion and stabilise the shoreline.

Economic importance

Estuaries are a nursery for many commercially important fish and crustacean species. Important commercial and recreational fishing estuary-reliant species include king prawn, black bream, blue swimmer crab and yellow-eye mullet. The fishing industry relies on healthy estuaries.

Recreational benefits

Fishing, ecotourism, boating and swimming are important recreational activities in estuaries.

1.4 Why is an estuary different from a freshwater coastal stream?

There are many factors that distinguish an estuary from a coastal stream, such as the influence of the ocean, the slowing of water flow and the spread into a broader, often shallower body of water. These create a very different environment to a fast flowing freshwater river or stream.

Tides

In estuaries, water flow is affected by tides. As the tide flows in, water levels rise. When the water reaches its highest level, it is considered **high tide**. After the point of high tide, the waters ebb away. When the water reaches its lowest point it is **low tide**.

Tides are caused by the gravitational forces of the Moon on the Earth. The lunar day is the time it takes for the moon to reappear at the same place in the sky, 24 hours and 50 minutes. Most locations in Australia and around the world have two high tides and two low tides each lunar day.

Tides affect both the direction and quantity of flow but also the level of salinity at a particular time. The water level difference between high and low tide varies from a few centimetres, up to 13 metres depending on the location and the moon phase.

Tidal movement affects:

- movement and mixing of fresh and marine water
- movement of litter and sediment
- movement of discharges from stormwater pipes and sewerage systems.

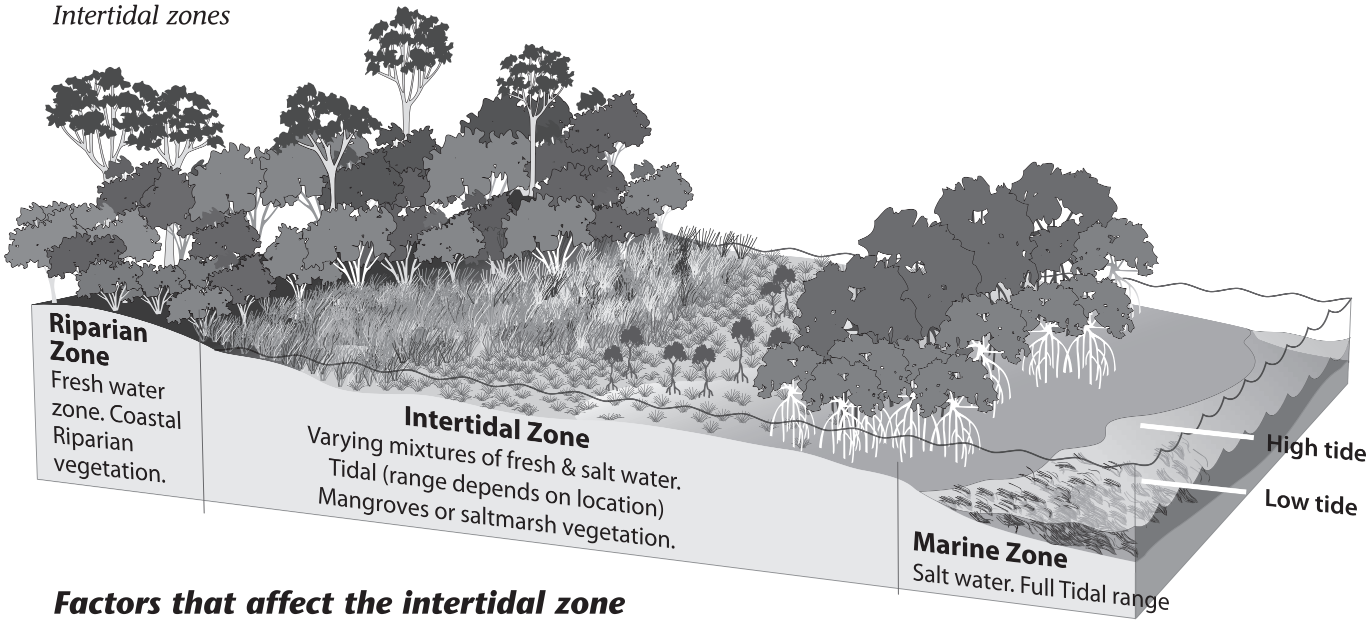
The ebb and flow of the tides affects nutrient availability, salinity, temperature, and oxygen. It is usual practice to monitor water quality on the ebb tide (going out).

The types of habitat available determine the animals that live within the estuary and to some extent, in the nearby coastal waters.

Intertidal zone

Tides particularly affect the organisms that live in the areas between low and high tide mark, the intertidal zone. To survive in this highly changeable habitat, an organism must have adaptations to daily changes in moisture, temperature, turbulence (due to water movement) and salinity.

Intertidal zones



Factors that affect the intertidal zone

- **Moisture**: The intertidal zone has saltwater at high tides and is exposed to the air at low tides; the height of the tide exposes more or less land to this daily tide cycle. Organisms must be adapted to both very wet and very dry conditions.

- **Water movement**: The turbulence of the water is another reason the intertidal zone is difficult to inhabit – rough waves can dislodge or carry away poorly-adapted organisms. Many intertidal animals burrow into the sand (e.g. clams), live under rocks, or attach themselves to rocks (e.g. barnacles and mussels).

- **Temperature**: The temperature ranges from the moderate temperature of the water to air temperatures that vary from below freezing to scorching hot.

- **Salinity**: Salinity varies with tides. In some parts of an estuary such as saltmarsh areas, salinity increases at high tide while at low tide, freshwater runoff can flow through the marsh. Organisms are exposed to varying degrees of moisture, but also to changes in salinity.

SECTION 2

Monitoring water quality in estuaries

The Waterwatch program includes testing of a number of water quality parameters to provide information about the health of the waterway under investigation. Some of these parameters will show different trends in the estuarine environment from those observed in freshwater systems.

This section outlines the differences which may be observed in test results for estuaries and the reasons for these differences. It also provides information about interpreting results according to water quality guidelines.

Included in this section: *Page*

2.1 How is water quality monitoring different in estuaries?

Monitoring water quality in estuaries produces different results to monitoring freshwater. Nutrient cycles, temperature, microalgae and macroalgae growth, dissolved oxygen and turbidity are all different because estuarine waters are salty. The tidal influence and its constant changes also affect water temperature, salinity, turbidity and to some extent, nutrients.

To monitor water quality over time in an estuary that is open to the ocean, it is important to choose a set tide, rather than a set time of day. Monitoring the outgoing tide will provide data on water travelling down through the catchment; monitoring on the incoming tide will provide information about the marine influence.

2.2 Temperature

Temperature is a measure of hot and cold and in Australia, is measured in degrees Celsius (°C). The main effect of water temperature on the environment is related to oxygen in the water. The amount of oxygen that water can hold decreases as the temperature of the water increases. If water gets too hot, there is less available oxygen for living things. Temperature also affects nutrient cycling and plant productivity.

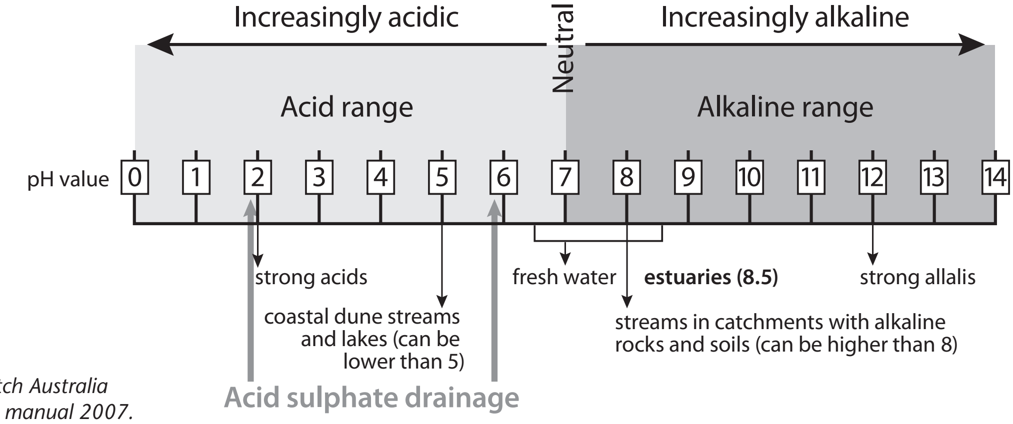
In estuaries, water temperature can be affected by:

- changes in the amount of freshwater (riverine) flow as deep water will be cooler than shallow water
- the extent of mixing between fresh and marine water by winds or tides
- discharges of water from power plants and municipal or industrial effluent, which are sources of thermal pollution in the coastal zone
- climate change and global warming.

2.3 pH

pH is a measure of the acidity or alkalinity of a substance. A difference of one pH unit is equivalent to a ten-fold change in acidity or alkalinity. An acceptable pH range for an estuary is between 7 and 9 according to the ANZECC guidelines. It is important to know when monitoring long term that a shift of 1 pH unit is quite significant.

pH guide



Source: *Waterwatch Australia national technical manual 2007.*

Acid sulphate soils

Many of the soils of low-lying areas around estuaries, especially in the north of New South Wales, were formed by deposition in shallow estuarine waters. Sediment may contain high levels of pyrite (iron sulfide) derived from seawater and when exposed to the air, it produces sulphuric acid. The steady leakage of acid can cause fish diseases and fish kills when storms and floods wash acid soils into the water.

Although recognised as a major concern to adjacent fisheries, acid sulfate soils are also detrimental to pasture growth and production from grazing.

2.4 Salinity

Salinity is a measure of the salt content of water. Salinity levels vary along an estuary depending on the mixing of freshwater and saltwater at a site. Generally, salinity increases along a coastal stream as it gets closer to the river mouth, where tidal influences are strongest.

A **freshwater stream** generally has an electrical conductivity (EC) of 200–300 µS/cm.

Estuaries have a much higher electrical conductivity than freshwater (typically from 20,000 to 40,000 µS/cm). As salinity increases, conductivity also increases. Seawater typically has a conductivity of 51,500 µS/cm. Many aquatic species can survive only within certain salinity ranges, so changes in salinity levels may result in changes to the variety and types of species present.

In coastal areas, salinity can be viewed as the major factor limiting species distributions as these vary significantly in relation to the level of salinity.

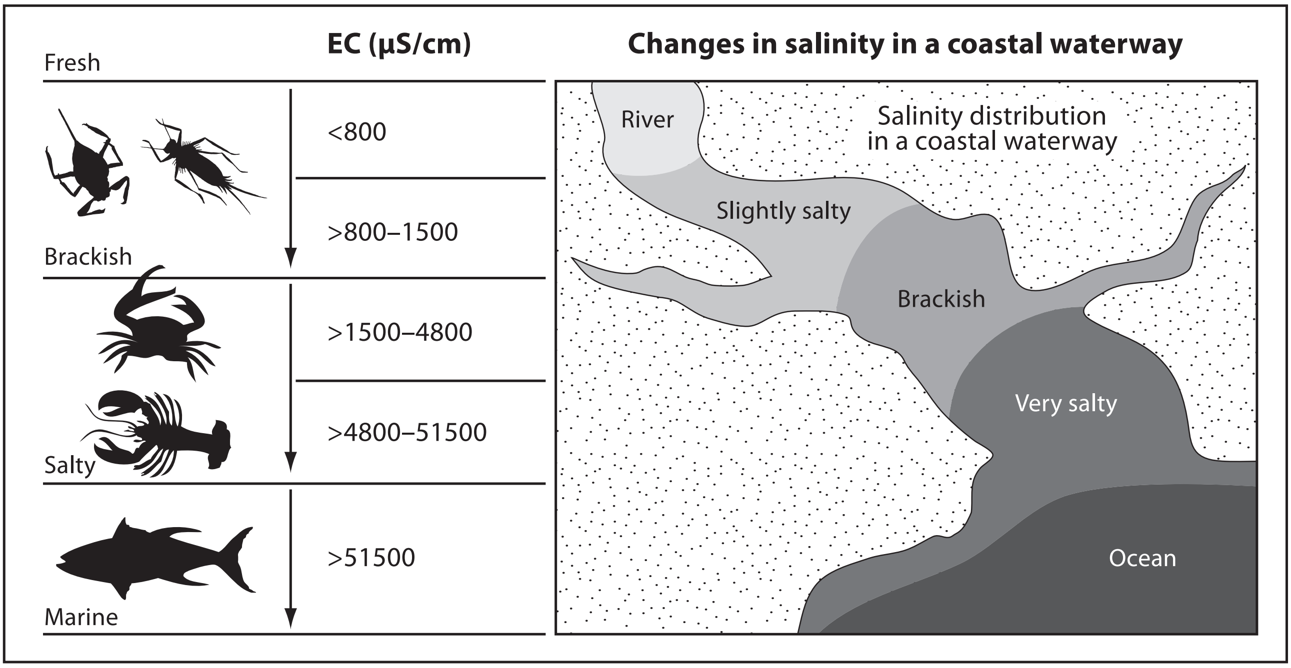
What causes salinity in coastal waters to change?

There are several influences on salinity in an estuary. Freshwater flows from the catchment reduce the concentration of salt in seawater and hence, the estuary. The amount of freshwater is affected by conditions in the catchment including rainfall patterns, structures, dams, plant types and cover, the shape, surfaces and size of the catchment. Salinity levels change with tidal flows and with mixing of freshwater and marine water by wind and currents.

Human activity can also affect salinity. If water is taken from a river for human use, e.g. for crop irrigation, there will be less freshwater flowing downstream and an estuary will become more saline. Stormwater can add freshwater and reduce normal salinity levels within an estuary. If channels are dredged, there may be an increase in the water exchange between the estuary and the ocean (increased flushing) with a greater influence of the ocean on the estuary than would have occurred naturally. Salinity is important in coastal waterways for the following reasons:

- The salinity of the water within the estuary provides an indication of the amount of freshwater that has mixed with seawater.
- Salinity affects the degree of mixing of water. As saltwater is heavier, it sinks to the bottom making it more saline than surface water. This will affect aquatic species that live at the bottom of the aquatic zone.
- Salinity affects the ability of an organism to live in this environment. This includes invertebrates that live on the bottom of the estuary as well as plants such as seagrass, saltmarsh species and mangroves.

Salinity in estuaries



Source: Adapted from Oz Estuaries – *Changes in salinity in an estuary*

2.5 Turbidity

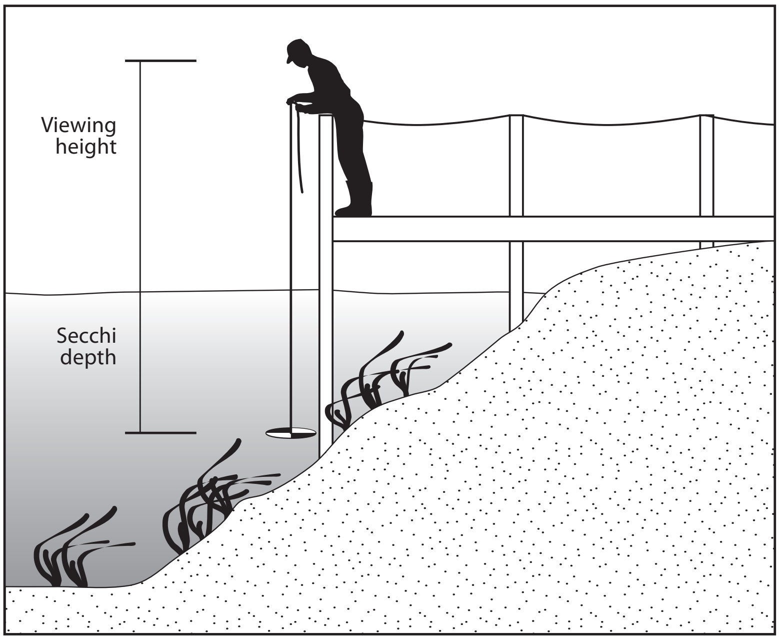
Turbidity is the cloudiness or muddiness of water. In general the more suspended, solid material there is in water, the higher the water's turbidity and the lower its clarity. Suspended material can be particles of clay, silt, sand, algae, plankton and other substances.

Why is it important?

Increased turbidity (i.e. increased suspended sediment) effects include:

- decreased light penetration into the water
- reduction in plant growth and oxygen production
- reduced breeding and survival of fish and other aquatic animals
- increased water temperature, causing lower oxygen levels
- degraded visual clarity of water.

Measuring water clarity with a secchi disk



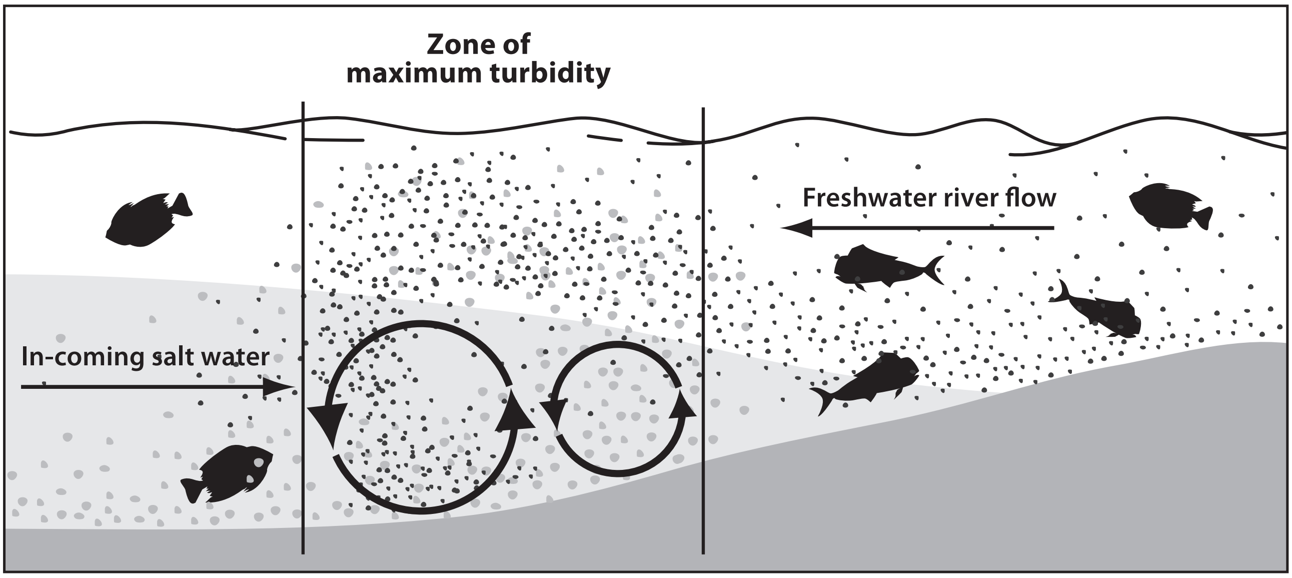
Source: Adapted from Waterwatch South Australia guidance manual, Coleman and Cook 2003.

The turbidity of a waterway can be increased by clearing riparian vegetation, the mismanagement of urban development and the resultant erosion carrying higher loads of sediment into the waterway. Estuaries are generally more turbid than marine and riverine waters due to the input of sediment from rivers, the presence of dense populations of phytoplankton, and the strength of tidal currents that prevent fine particles from settling. As light does not penetrate to great depths, bottom dwelling plants are largely restricted to the margins of estuaries. There may be marked seasonal influences on turbidity in estuaries caused by changes in river flow. Floods generally increase turbidity levels.

Turbidity is affected by salinity. Salt settles sediment, so the presence of salt in estuaries has the effect of reducing turbidity. Turbidity may be low in surface waters but may be high at the intersection between freshwater and seawater, and may vary with depth.

The highest turbidity levels will occur where freshwater meets seawater. This is due to the movement of water in and out of the estuary by tides, causing fine particles to mix and be stirred up.

Turbidity zones (Source: Adapted from Waterwatch Australia national technical manual, 2007).



2.6 Rate of flow

Rate of flow is the volume of water passing a particular point in a stream at any given time. Flow rates affect water temperature, dissolved oxygen, turbidity, salinity and the concentrations of pollutants.

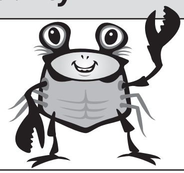
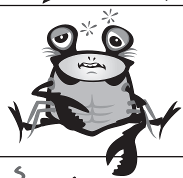
2.7 Interpreting water quality results in estuaries

Water quality guidelines

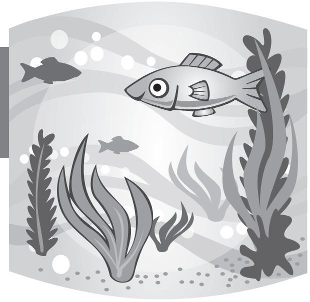
Water quality guidelines are recommended values or ranges for water quality parameters. They help to identify when changes in a parameter may have the potential to cause an environmental problem. This may trigger further investigation and hence is called a ‘trigger’ value. Your local area may have its own specific trigger values. These can only be developed through analysis of data from long-term, regular monitoring.

Water quality at your site

Waterwatch provides an assessment of water quality for a range of parameters at your site based on both water quality and ecosystem health guidelines.

Water quality	Ecosystem
Healthy 	Healthy ecosystem – plants and animals adapted to natural environmental conditions
Fair 	May affect estuary health – plants and animals at the site may be at risk
Poor 	Ecosystem at risk – aquatic plants and animals at risk may be at risk

Water quality paramter	Estuary health		
	Healthy	Fair	Poor
Temperature ˚C	No trigger values affected by tides		
pH	7–9	No trigger value	<7 – >9
EC µS/cm or mS/cm	No trigger values affected by tides		
Turbidity NTU	<10	10–20	>20 (may be influenced by tides)
PO_4 mg/L	<0.02	0.02–0.3	>0.3
DO % sat.	80–110	No trigger values	<80 or >110



SECTION 3

Introduction to estuarine habitats

Habitat investigations provide information about the health of an estuary. By collecting information over time, a picture can be built up about an estuary, including its natural fluctuations. When changes occur, the type, size and frequency of the change can be measured against past data and observations. The change can be monitored and linked to possible causes. This is highly valuable information for natural resource managers, who can then provide assistance in addressing the causes.

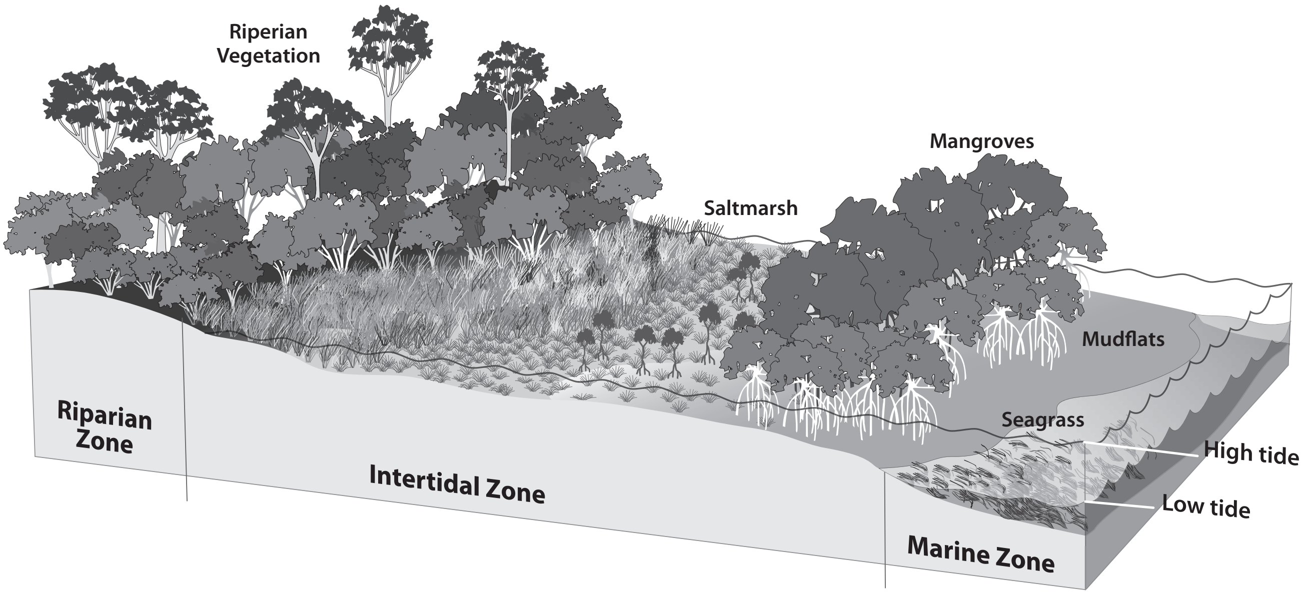
This section describes the different habitats found in and around estuaries and the types of creatures found in them. The important habitats of the riparian zone, saltmarshes, mangroves and seagrass are covered.

Included in this section: *Page*

3.1 Habitat types in estuaries

An estuarine habitat is a place within the estuary that provides food and shelter for living things. In an estuary, changes occur due to the influence of fresh and saltwater, just as they do in the intertidal zone. The salinity of the water determines whether the habitat provides food and shelter for fresh or saltwater species, or organisms adapted to both. Hence, the influence of the ocean within estuaries affects the types of plant and animal species found there.

Cross-section diagram of habitat types



Zone	Habitat	Features
Marine	Seagrass/ mudflats	Covered by tides for most of the time. May be uncovered twice each day for short periods
Intertidal	Mangroves	Covered by tides twice each day and exposed for greater periods of time
	Saltmarsh	Covered by tides for shorter periods, less often
Riparian	Riparian vegetation	Never covered by tides, unless from an extreme weather event (floods)

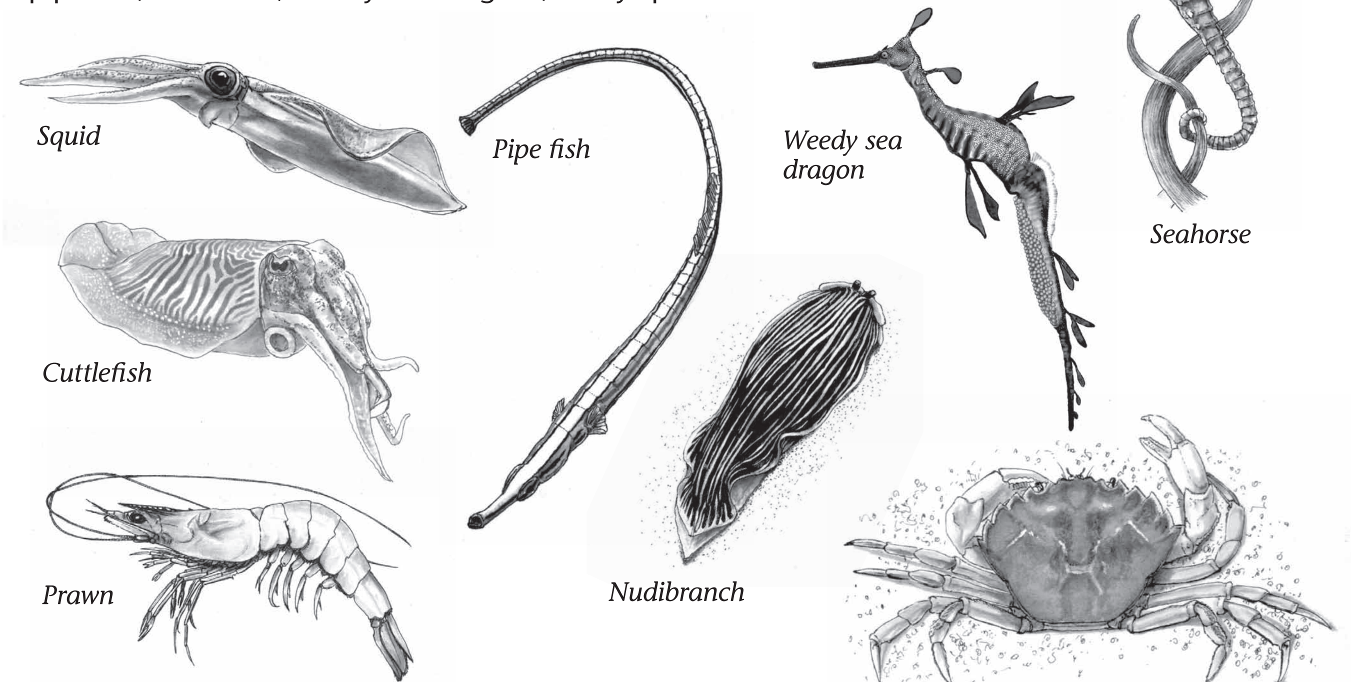
Adaptations

The wide range of different habitat types and rapidly changing conditions in an estuary require its inhabitants to develop specific adaptations to survive. In the passage of a few hours, conditions can change from salty to fresh, and wet to dry, and such huge changes require species to have special features called 'adaptations' not only to survive, but also to be able to reproduce.

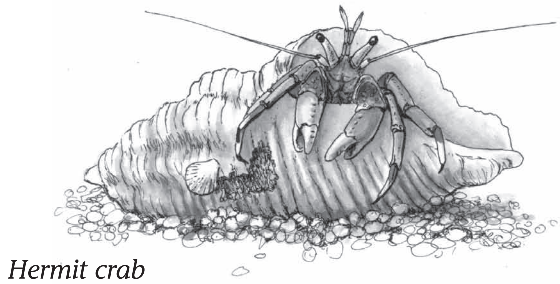
Habitat characteristics and estuary species

Seagrass: salty and wet

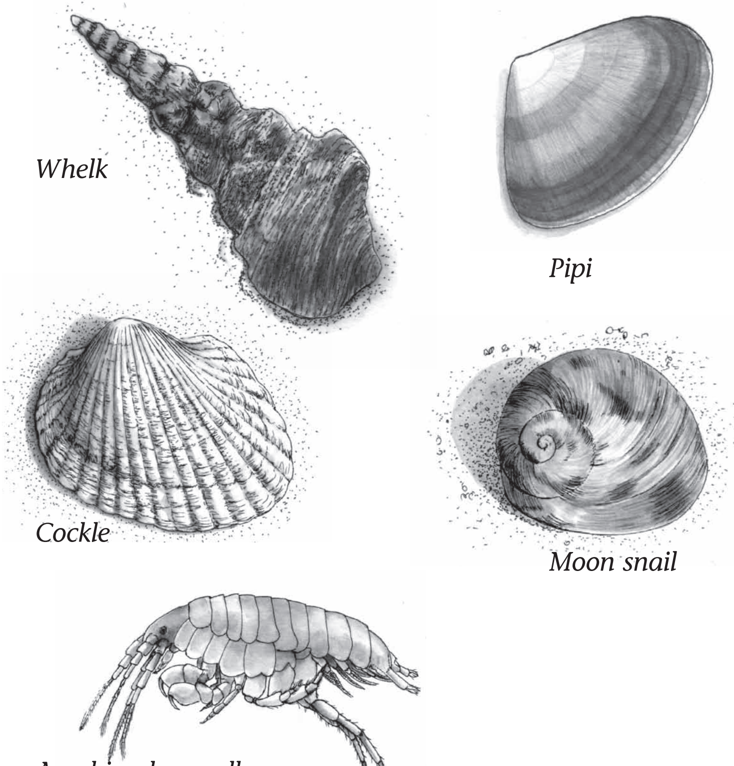
Estuary species: nudibranchs, sea slugs, squid, octopus, cuttlefish, prawns, pipe fish, seahorses, weedy sea dragons, many species of crab and fish.

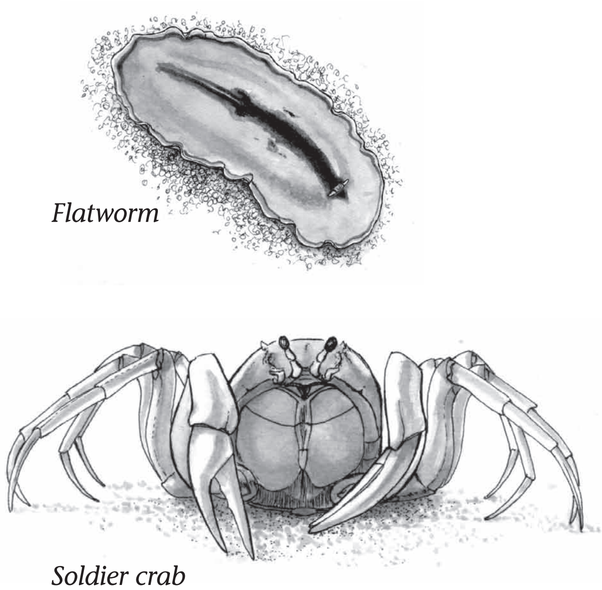


Sand and mudflats: salty and usually wet



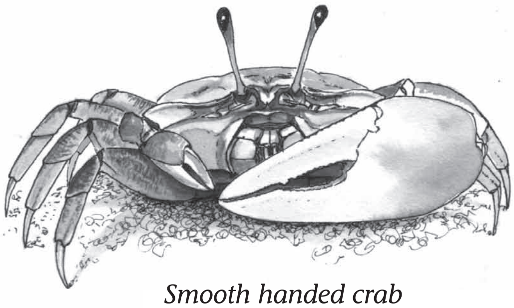
Estuary species: snails, whelks, cockles, pipis, isopods, amphipods, flatworms, ragworms, many species of crabs, small sand-dwelling macroinvertebrates.





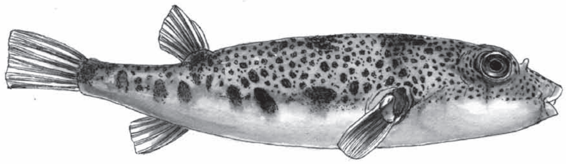
Mangroves: salty and wet and occasionally dry

Estuary species: mangrove air breather, snails, whelks, many species of crabs, oysters, isopods and fish.



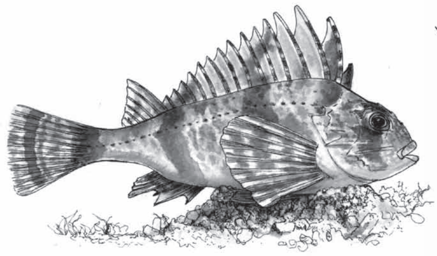
Smooth handed crab

Sydney rock oyster

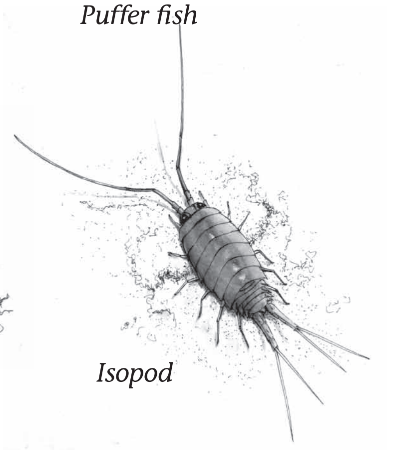


Puffer fish

Fiddler crab



Fortescue fish

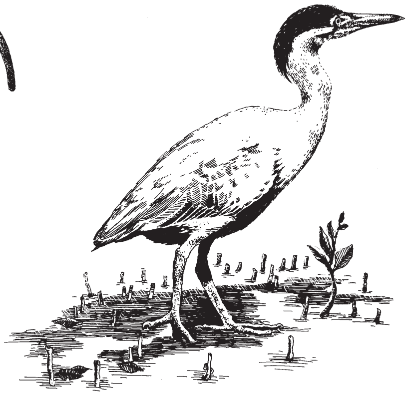


Isopod

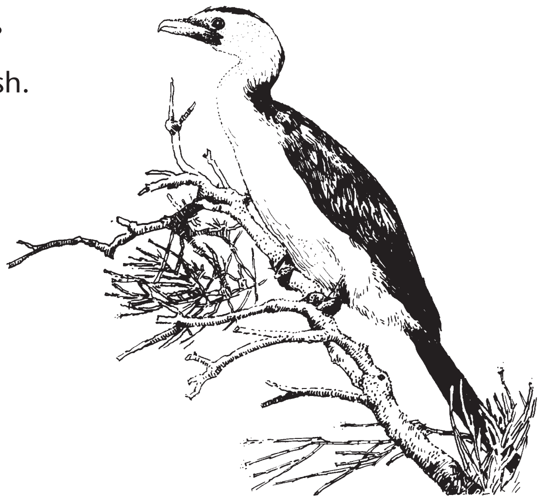
Saltmarsh: salty and fresh water, wet during high tide

Estuary species: snails, crabs, birds including migratory birds, fish.

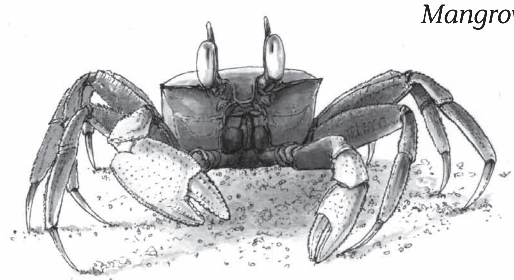
Black headed ibis



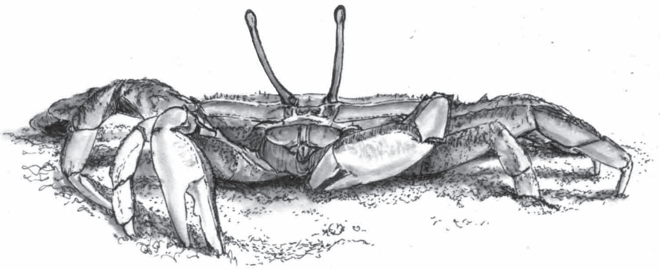
Mangrove heron



Little pied cormorant



Stalk eyed crab



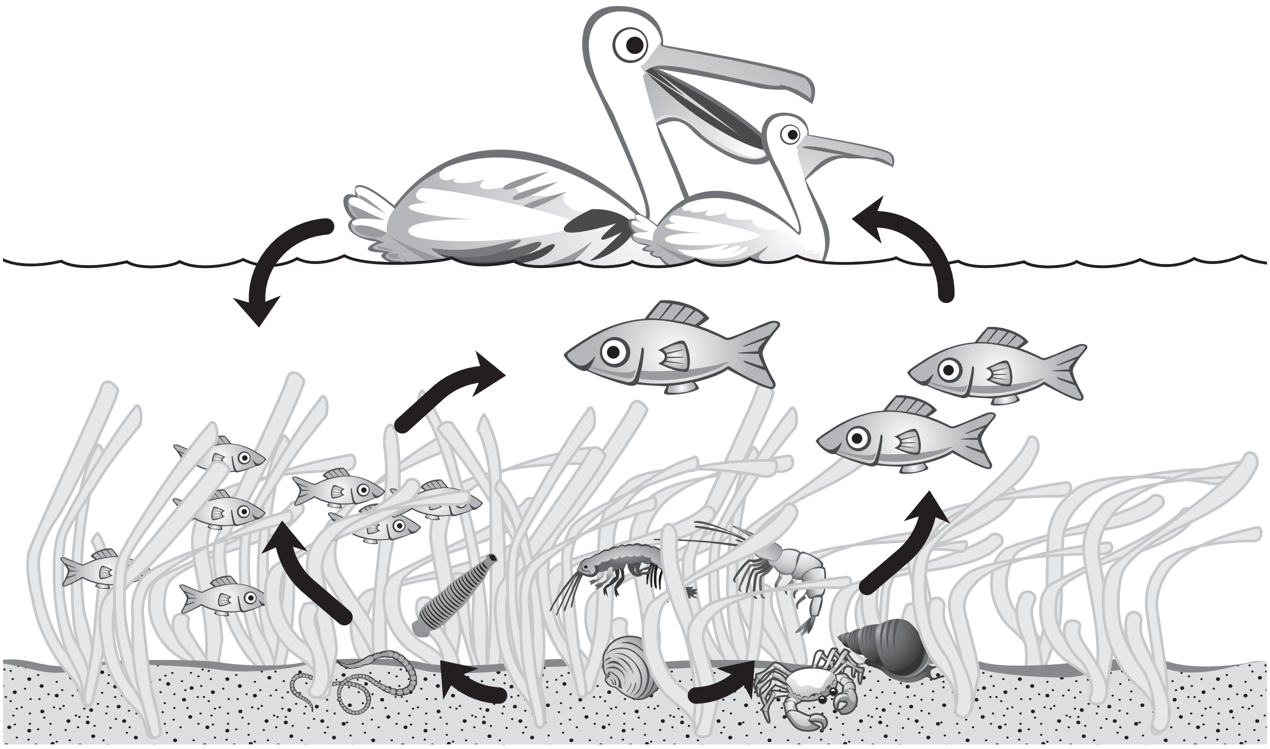
Sentinel crab

Source: Bird illustrations by Gavin Gatenby, courtesy of DECCW

3.2 What does an estuary mean to its wildlife?

An estuary can represent many things to different wildlife:

- **Nursery**: Many species such as fish, crustaceans and invertebrates spawn here because it is protected from oceanic waves and there is a plentiful supply of food and nutrients.
- **Restaurant**: Many small animals live in estuaries. Snails, isopods, insects, fiddler crabs are just a few. Many birds feed on the high protein species found in mangroves, mudflats, and saltmarsh and seagrass beds.
- **Food chain**: Plants and animals in an estuary depend on each other to meet their food requirements. For example, invertebrates may feed on seagrass and may then be eaten by crustaceans, small fish or birds. This is called a food chain.
- **Link**: Saltmarsh and mangroves are an important link between the ocean and the land; they are the transition zones between freshwater from the catchment and saltwater from the ocean.



3.3 Investigating estuarine habitats

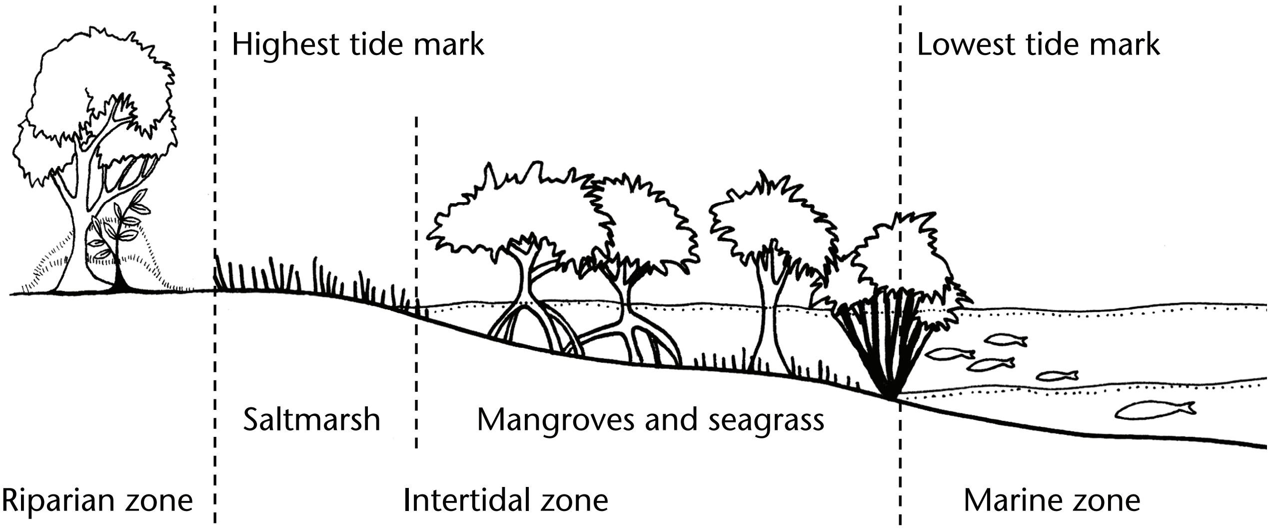
Investigating estuarine habitats involves gaining an understanding of the influences and processes that have helped to shape the estuary. Habitat assessments build skills in observation and recording and involve measurements and graphs that help to track changes. Taking photographs or sketching details of flora and fauna provides qualitative data, which is also useful information for tracking changes over time and providing an indication of the health of an estuary.

Observations of changes at your estuary provide a valuable contribution to understanding ecosystem change and help manage the catchment.

3.4 Riparian habitat

'Riparian' means adjacent to, or in contact with a waterway. In an estuary, riparian vegetation occurs above the high tide level. This means that the riparian area does **not** include mangroves and saltmarsh. The plants of the estuarine riparian area tend to occur in zones according to the level of salinity. In the lower parts of the riparian area, plants are usually more salt tolerant.

Riparian and intertidal vegetation zones



Riparian vegetation around many estuaries in New South Wales has been cleared for tourism, urban and agricultural purposes. Use of this habitat type by humans and livestock has caused severe degradation. Bank erosion, soil compaction and a lack of regeneration of plant species in their respective zones are just a few of the consequences. Disturbance of these ecosystems has allowed the infiltration of weeds and pests.

Monitoring of this vegetation is an essential part of estuarine assessment and a good indicator of estuarine health and stability.

Benefits of riparian vegetation

- **Buffer**: Estuarine riparian vegetation can act as a buffer between nearby land use and aquatic ecosystems, filtering sediments and reducing the transfer of phosphorus, nitrogen and organic matter to the water. This helps to improve water quality.
- **Bank stabilisation**: Root systems stabilise banks in times of high flow or king tides, minimising bank damage, soil loss and erosion.
- **Lowering of watertable**: Riparian vegetation may help to lower the watertable, which in turn can reduce the flow of salt into streams.
- **Biodiversity**: The riparian zone is generally more diverse than surrounding habitats due to the higher moisture availability and soil conditions.
- **Favourable microclimates**: The overhanging vegetation of this zone can also shade the water, lowering the water temperature and facilitating more favourable conditions and habitats for aquatic organisms.

3.5 Saltmarsh

The distribution of plants (and animals) in the saltmarsh zone is influenced by tides, rivers and human activity. Saltmarsh may include shallow pools that provide habitat for salt tolerant freshwater macroinvertebrates and saltwater species.

Saltmarsh plant communities are dominated by herbs, sedges, grasses and low shrubs. The main saltmarsh species found in New South Wales are samphire, salt couch and rushes such as sea rush (*Juncus kraussii*), and weeds such as spiny rush (*Juncus acutus*). These plants die and regenerate, adding large amounts of decaying plant matter or detritus to the food chain. Scavengers and bacteria break down the decaying plant matter which provides nutrients and minerals for further plant growth and algae. This process forms the basis of a complex food web including fish, crabs, shellfish and birds.

Saltmarsh is generally flooded with saltwater during high tide. At low tide, land becomes exposed and it is possible for freshwater to flow into the saltmarsh. This means that species living in the saltmarsh are exposed to variations in temperature and moisture, and they are also subjected to large changes in salinity. Some species like crabs burrow into the mud at low tide. Some saltmarsh species, like snails, move away from the incoming water. Species that live in this zone have adapted to both aquatic and terrestrial conditions, as changes can occur within the same day. The changes that occur within a saltmarsh are called **zonation**. It is often described as:

- **high marsh** – covered briefly each day by tides
- **low marsh** – beneath the level of the tide for many hours each day.

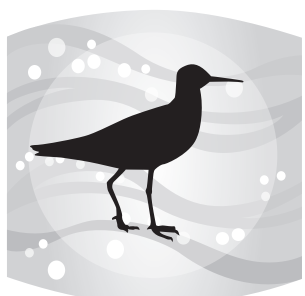
Healthy saltmarsh communities show changes from the lower marsh to the upper marsh. Vegetation patterns may change in response to changing soil salinities or pH, tides or climatic patterns.

Saltmarsh is fragile

- Changes may take place due to fluctuations in water quality, soil salinity or flow patterns that may be influenced by structures such as flood gates.
- Monitoring change is very important as a decline in number of species and their distribution may indicate stress.
- Investigations of plant cover and species dominance along a transect line will provide useful information about the health of a saltmarsh.

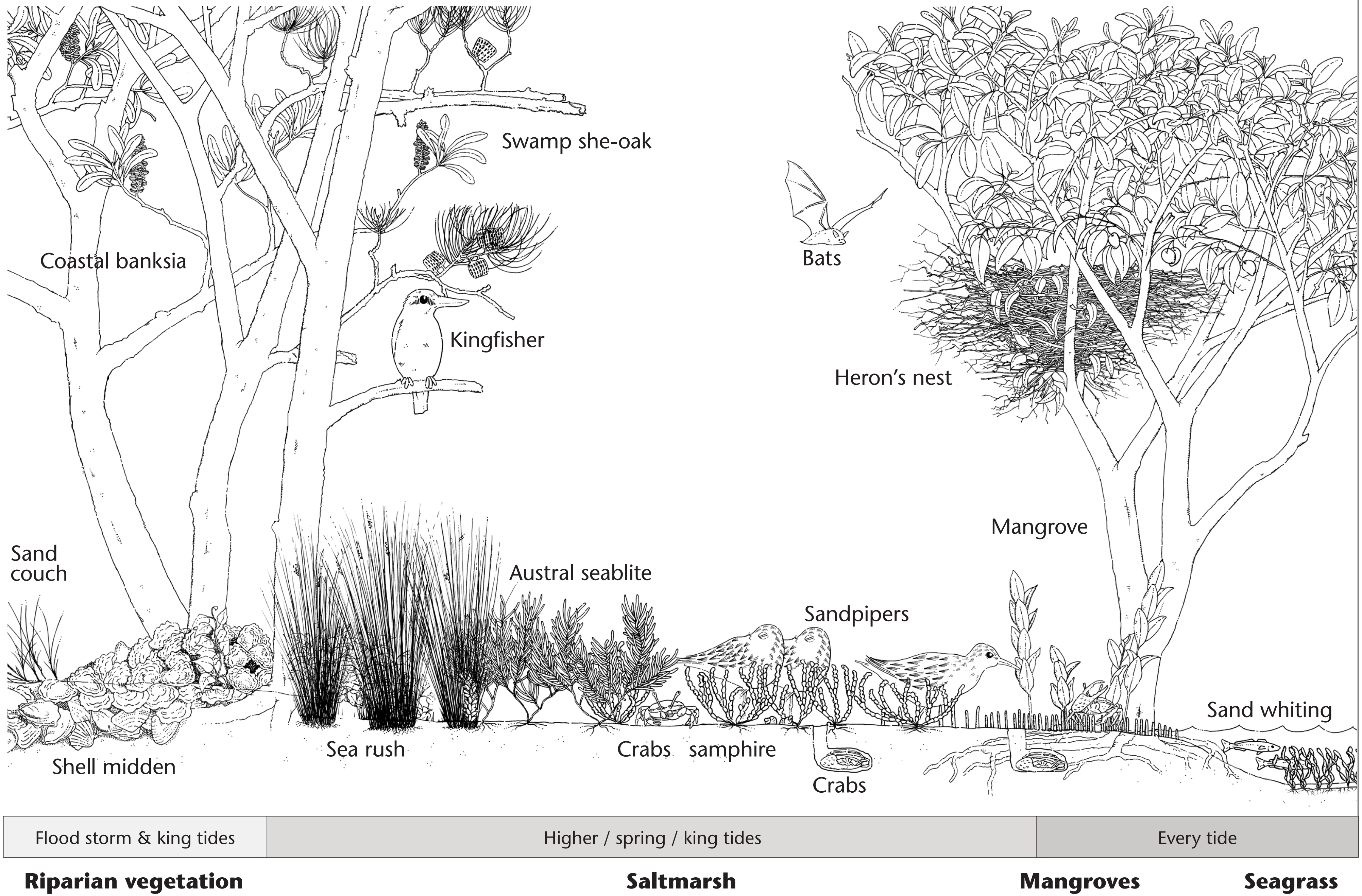
Selecting a monitoring site for saltmarsh

- Select a site with safe and easy access, even in rain events.
- Use the edge of a boardwalk or walking path as the transect line because walking on saltmarsh damages it. Recovery can take a long time. Using a path or structure will minimise disturbance and make the activity easier on participants.

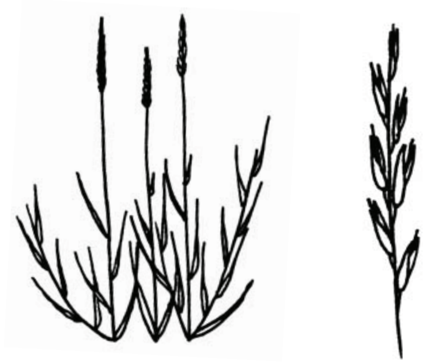
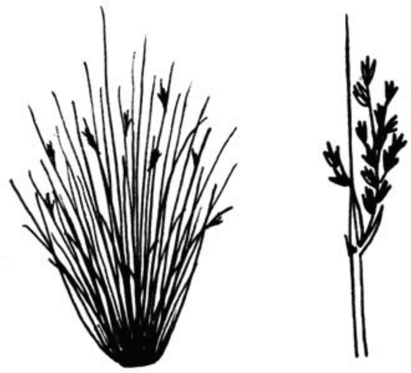
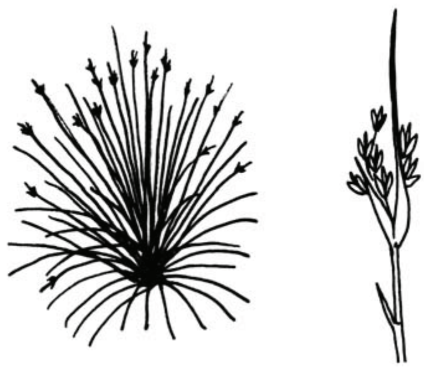
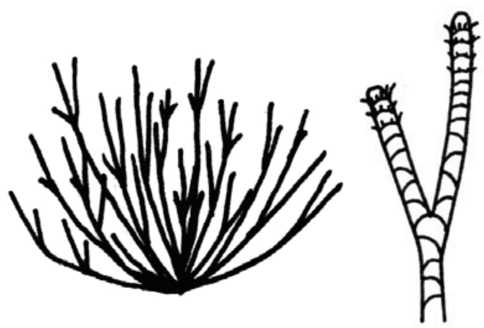


Saltmarsh cross section

Source: courtesy Hawkesbury Nepean CMA



Common saltmarsh species

Name	Distinguishing features	Appearance
Salt/marine/ sand couch *Sporobolous virginicus*	• Perennial ground cover grass • Forms dense mat/tufts often spreading over large areas • Grey/green to yellow - greener in the summer months	
Sea rush *Juncus kraussii*	• Tussock forming perennial • Leaves 40-50 cm long • Green with golden/brown sheath • Clustered flowers 4–20 cm long: straw to reddish brown	
Spiny rush *Juncus acutus* (introduced)	• Large clumping perennial • Grows to 120 cm tall • Tough leaves and flower stems tapering to sharp points	
Red samphire *Sarcocornia quinqueflora*	• Perennial herb/shrub (usually below 30cm tall) • Grows in sand; sandy loam; clay; moderately saline soils • Found in swamps; estuaries; salt lakes	

3.6 Seagrass

Seagrass is a flowering plant that lives in marine (very salty) and brackish (slightly salty) water. Seagrass is usually found in sheltered bays, lagoons, lakes and estuaries. It needs sunlight, good water quality and nutrients to grow. Seagrass plants take their nourishment from the sediments they live in and drop their leaves at certain times of the year. They use nutrients to grow and when their leaves drop, they take some of these nutrients with them. Fish and seahorses use seagrasses much the same way as birds and insects use the trees and plants in your garden. Without these plants, the animals will go elsewhere, or may even die.

Seagrass is important as it provides:

- habitat
- food
- shelter
- a nursery area for fish and other marine animals
- nutrient absorption and exchange
- a good indication of environmental change.

Seagrass also stabilises marine sediments, lowers turbidity by settling sediment and improves water quality by removing nutrients. In comparison with unvegetated habitats there is a large abundance and diversity of animals associated with seagrass beds. These include mobile and fixed animals and microscopic bacteria.

Life in seagrass

Mobile animals

These include:

- animals living in the sediment, among the rhizomes of the seagrass, e.g. worms or polychaetes
- smaller, mobile animals that move across the surface of the sediment, e.g. molluscs or snails
- larger, mobile animals that are associated with the entire seagrass bed, rather than individual shoots, e.g. pipefish and seahorses.

Animals that are fixed

These include animals permanently attached to the seagrass stems or leaves, e.g. epizoans.

Microscopic bacteria

These colonise any exposed area of seagrass.

What affects seagrass?

Natural processes and human activities frequently cause condition changes in seagrass beds. Productivity occurs mostly in the warmer months, with the timing varying among species; however, overall growth rate depends on the turbidity of the water, temperature, and nutrient concentrations.

Seagrass is directly affected by water quality.

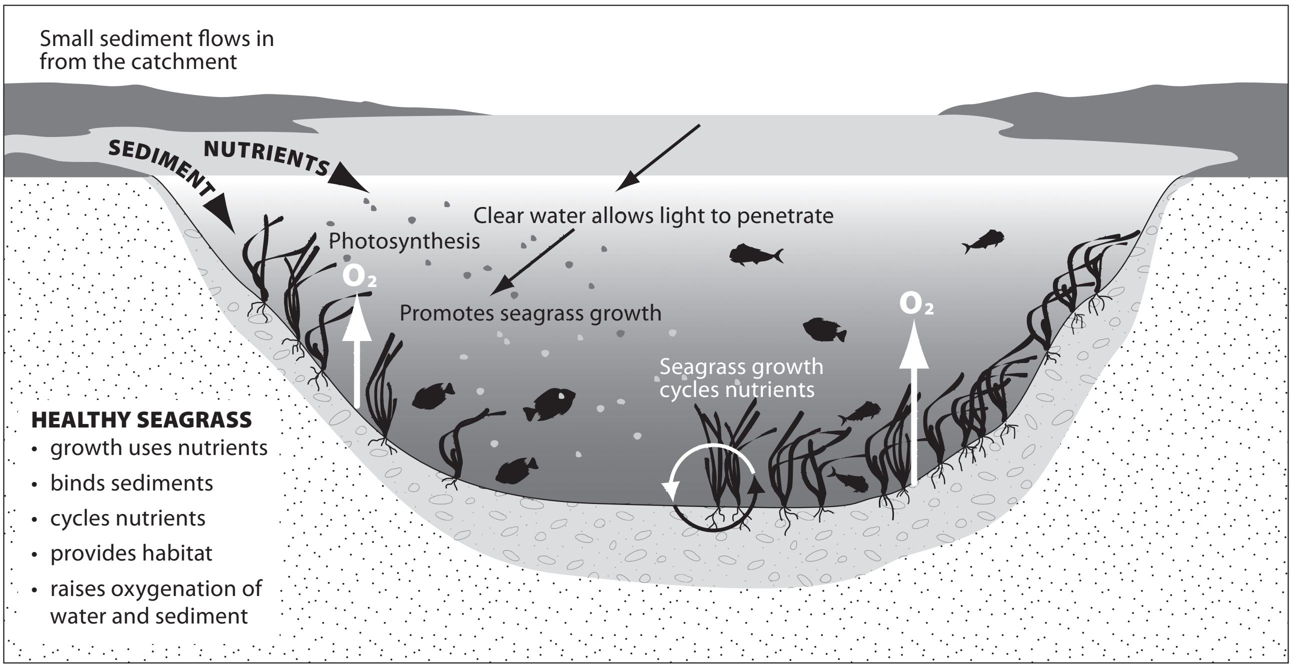
Stormwater, rainfall and other water running off the surrounding land contains nutrients and sediments. In small amounts, nutrients and sediments actually benefit seagrass and encourage its growth. However, with more people living in these coastal catchments, levels of nutrients, sediments and other chemicals entering the waterways have increased significantly.

High levels of nutrients promote the growth of epiphytic algae (algae attached to seagrass blades) which can interfere with seagrass photosynthesis. Eventually, epiphytic algae can smother and kill the seagrass. High levels of sediment suspended in water reduce the amount of light received by seagrass, affecting its growth. Extremes of temperature, pH and salinity can also affect seagrass health. Storms can have an impact as waves can remove seagrass from the sediments.

Seagrass communities are susceptible to changes in water and environmental quality, which makes them a useful indicator of ecosystem health. The degradation or loss of seagrass beds can be an indication that the health of an estuary has been compromised.

Seagrass can also be affected by human activity such as boating and dredging.

Cross-section diagram of factors affecting seagrass health



Source: Adapted from Waterwatch Australia national technical manual, 2007.

Mapping and monitoring of seagrass beds

Seagrasses are sessile (fixed) and easily measured and because they occur downstream of the catchment they demonstrate timely responses to impacts from upstream activities. When seagrass beds are unhealthy, the ecosystem becomes less productive, less oxygen is produced and there is a decrease in food, shelter and nursery grounds for many species. Monitoring and mapping change in seagrass beds over time is a very useful tool for natural resource management.

Local authorities have been conducting aerial and satellite mapping of natural resource areas for a number of years. However, the mapping events and ensuing interpretation can often take several years to be available to the public and many changes can occur during this time. The scope of mapping activities is often regional and can miss small but significant areas of seagrass. As the environment is constantly changing, monitoring in local areas can fill in the gaps. Environmental monitoring programs allow the community to become the eyes of the catchment, observing changes and collecting data over time.

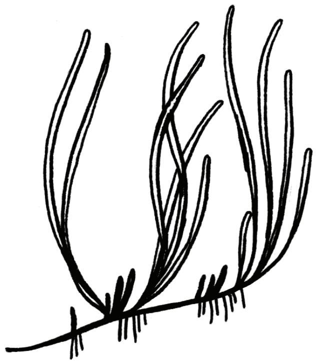
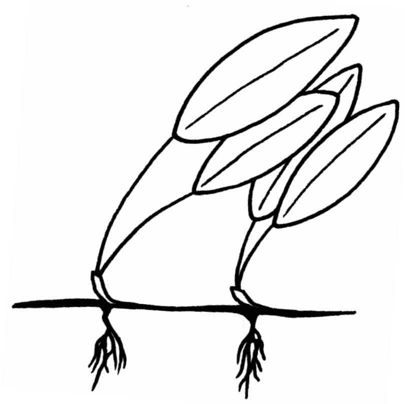
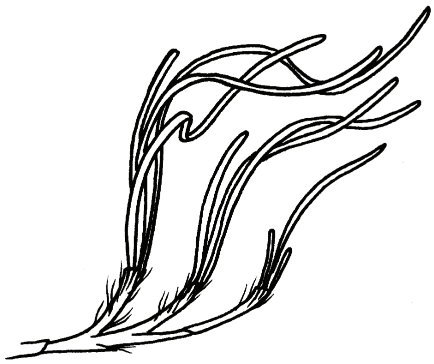
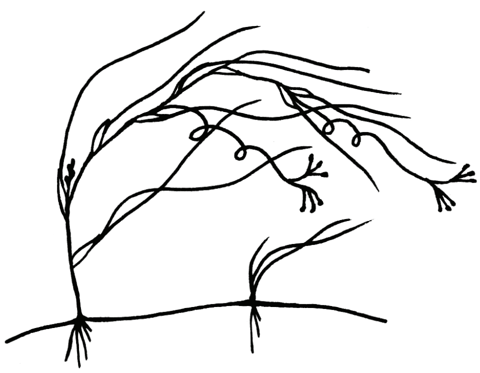
Community seagrass monitoring

Water quality is an indication of what may be affecting seagrasses and is important in gaining a better understanding of catchment health. By placing a seagrass monitoring site where water quality testing is also being conducted, the data collected may be useful to indicate changes at a small scale. Simple techniques for monitoring seagrass distribution can be found in the *Waterwatch Estuary Field Manual*.

The main seagrass species found in New South Wales are:

- *Zostera capricornii* (eelgrass)
- *Ruppia megacarpa* (sea tassel)
- *Halophila ovalis* (paddleweed)
- *Posidonia australis* (strapweed).

Common seagrass species

Name	Distinguishing features	Appearance
Eelgrass *Zostera* sp.	• Leaf with 3-5 parallel veins • Cross veins form boxes • Leaf tip smooth and rounded, may be darker at the tip • Rhizome usually brown or yellow in younger parts • Leaf size can vary • Colour varies from bright green to brown • Leaves rise directly from rhizome	
Paddleweed *Halophyla ovalis*	• Small seagrass with upright stems • Rounded leaves in pairs • Light green leaves (4 cm long; 2 cm wide) • Stems and leaves come off runners • Runners occur below sediment surface and also bear roots	
Strapweed *Posidonia* sp.	• Large strap like leaves - thick and stiff with rounded tips • Leaves are 45 cm long; 15–20 mm wide • 14–20 longitudinal veins • Leaves generally bright green • 3–5 leaves rising from leaf base at rhizomes	
Sea tassel *Ruppia* sp.	• Long slender leaves (0.5–2 mm wide) • Highly branched stem • Leaves are 50–200 mm long • Generally dark green	

3.7 Seagrass wrack

Some seagrass species (*Zostera*) shed some of their leaves annually, just like trees. Seagrass wrack refers to the shed or detached leaf material of seagrass plants.

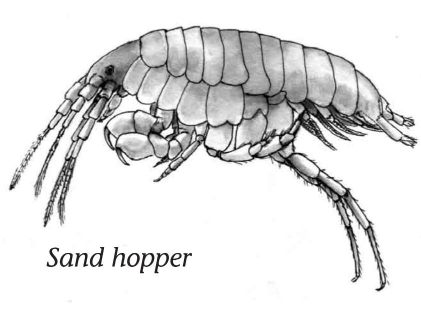
Seasonal growth of seagrasses plays a major role in the production of wrack within estuaries. Summer is the main growth period for seagrasses, whilst growth is reduced in winter. The majority of wrack is produced during the winter die-back period as the leaves are shed. The leaf blades are initially buoyant, then sink and accumulate in drifts on the bed of the estuary. Water currents, wind and wave activity mobilise the detached leaf blades, moving material onto the shore. This process is entirely natural and common to estuaries around the Australian coastline.

Shores that face prevailing winds are likely to receive an increased amount of wrack compared to shores that are sheltered from the wind. Prior to human settlement, wrack was deposited onto gently sloping foreshores where it would break down and release nutrients back into the natural environment. Where foreshores have been modified with steeper slopes or seawalls, wrack cannot get out of the water. It can become waterlogged, sink to the bottom and break down anaerobically (without oxygen). This process produces the smelly, black sediments found in some locations around many Australian estuaries (e.g. Lake Macquarie in NSW). While this process is also natural, it would be less of a problem if wrack could break down in air, on shore.

The importance of seagrass wrack

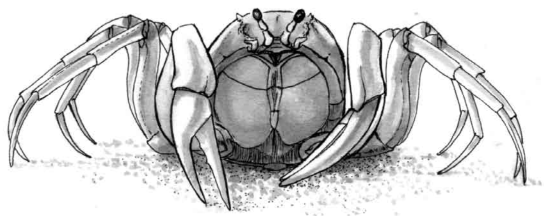
Seagrass wrack has value in the maintenance of beaches and estuarine shorelines. This includes:

- **Shoreline stabilisation**: Wrack may accumulate at the high tide mark where it absorbs the energy from small waves. This helps to reduce erosion from the shoreline by stabilising the sand. Another important action of wrack is the trapping of fine sediments flowing into the estuary after heavy rainfall.
- **Habitat provision**: The wrack provides complex habitat that is home to a variety of animals. Studies have shown that the species diversity in wrack is higher than adjacent areas, both above and below the tide line. Wrack that accumulates at the water's edge also provides shelter for species of fish and crustaceans that are important to commercial and recreational fishing, thus extending the total area of available nursery grounds.
- **Start of the food chain**: Wrack provides food at both ends of the food chain. At the lower end it provides food for small organisms such as amphipods (sand hoppers) and small crabs, which in turn are a favourite food for juvenile fish. As the wrack breaks down nutrients are slowly leached into the sand. This provides food for small species of algae that grow and in turn are eaten by worms and then fish. Wrack is also important to indigenous and migratory waterbirds in providing an abundance of food (small creatures feeding on wrack) and is essential to their survival.



Sand hopper

Seagrass wrack is also harvested for a variety of purposes throughout Australia and overseas including use as a soil improver and/or garden mulch.



Soldier crab

3.8 Mangroves

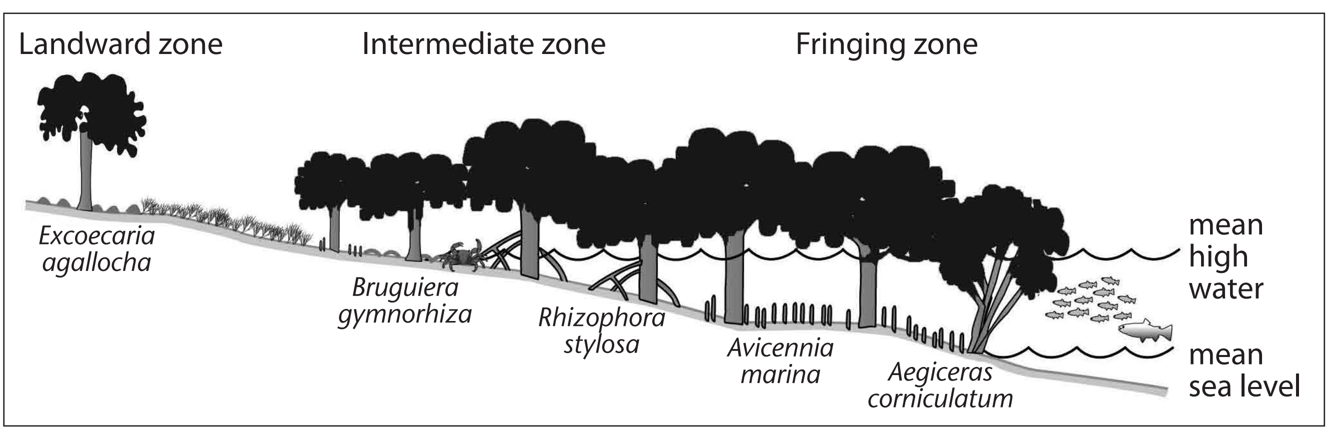
Mangrove ecosystems

Mangroves are specially adapted trees that grow in soft sediments within the intertidal zone and support productive ecosystems. The litter from mangroves provides food for invertebrates such as crabs, but is mostly decomposed by fungi and bacteria. As this material is broken down, small crustaceans, molluscs and other invertebrates consume the particles. The complex aerial root systems of mangrove trees provide a home and shelter for barnacles, oysters, snails and crabs.

Mangroves of New South Wales

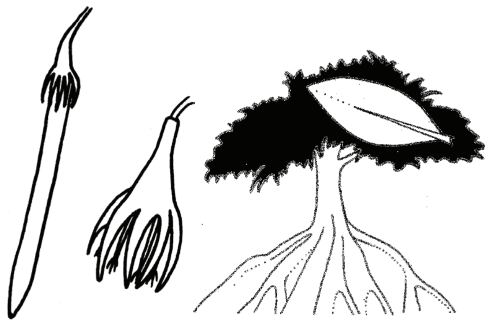
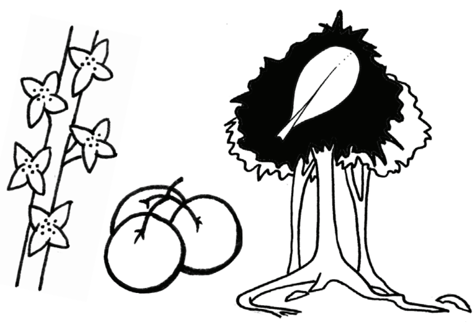
There are five species of mangroves in New South Wales. The grey mangrove and the river mangrove are the most common on the NSW coast. The river mangrove *(Aegiceras corniculatum)* is a widespread shrub found from the Tweed River, south to Merimbula Lake. The grey mangrove *(Avicennia marina)* is a large tree found along the entire coast. Three others, the red mangrove *(Rhizphora stylosa)*, large-leaved mangrove *(Bruguiera gymnorrhiza)* and milky mangrove *(Excoecaria agallocha)*, are located only in the northern estuaries of the state. Mudflats are often found in conjunction with mangroves.

Mangrove varieties



Source: Department of Industry and Investment

Mangrove identification (Source: Department of Industry and Investment).

Name	Distinguishing features	Distribution in NSW	Appearance
River mangrove *Aegiceras corniculatum*	• Occurs in fringing tidal zone • Smooth dark brown bark • Shrub/multi-stemmed tree (1–3 m) • No above ground roots • Alternate oval leave a (>7 cm); rounded tips • Curved tapering fruit with pointed tip • Salt deposits on leaves	Tweed River to Merimbula River	
Grey mangrove *Avicennia marina (variety australasica)*	• Occurs in fringing to intermediate tidal zone • Smooth, pale grey bark • Tree (2–12 m) • Pneumatophores (vertical roots) • Opposite pointed leaves; pointed tip; pale grey undersurface • Small pale orange, scented flowers • Bulb like fruit (1–4 cm)	Entire coast	
Red/stilted mangrove *Rhizophora stylosa*	• Occurs in fringing to intermediate tidal zone • Grey/black rough bark • Tree (2–8 m) • Prop/stilt roots • Opposite dk green glossy leaves (10–15 cm); broad with sharp abrupt point • Yellow white flowers with hair petals • Long green/brown fruit; narrow; tapered (20–30 cm)	Tweed River to Macleay River	
Large leafed mangrove *Bruguiera gymnorhiza*	• Occurs in intermediate to landward tidal zone • Dark brown rough bark • Tree (2–6 m) • Buttress trunk and exposed knee roots • Opposite large leaves (10–20 cm) • Red flower; orange petals • Green cigar shaped fruit (10–20 cm))	Tweed River to Clarence River	
Milky/blind-your-eye mangrove *Excoecaria agallocha*	• Occurs in intermediate to landward tidal zone • Grey slightly rough bark • Tree (2–6 m) • Emergent roots • Alternate leaves (6–10 cm) • Exudes milky sap • Male and female flowers on different trees • Fruit has peppercorn like seeds	Tweed River to Manning River	

3.9 Mudflats and sandy basins

Sandy and muddy sediments occupy large areas of most estuaries. The sediment type may vary considerably and can range from marine sand, in areas exposed to wave action, to silty mud in more sheltered areas.

Sandy sediments have spaces between sand particles and provide habitat for small invertebrates. These coarser sediments are also more readily oxygenated than muddy sediments and invertebrates such as molluscs, bivalves and polychaetes (worms) can therefore burrow to a greater depth. Silty mud areas provide habitat for prawns, bivalves, polychaetes and small crustaceans which feed on the bacteria and algae that grow on top of the sediment.

3.10 Estuary food chains

Estuaries provide habitat and a supply of food for a variety of small animals.

Estuary food chains show the feeding relationship between the different organisms that live in an estuary. They show the flow of matter and energy through the ecosystem. A food chain usually begins with producers which are eaten by herbivores which in turn are eaten by carnivores.

Producers

Producers, or plants, produce their own food, usually through the process of photosynthesis. In an estuary, these plants include phytoplankton, seagrasses, saltmarsh plants and mangroves.

Plankton are microscopic organisms that drift freely in the water and can have both animal and single-celled plant components.

Consumers

Plants are eaten by other organisms called consumers, which are classified by the food they eat. They include:

- herbivores – eat plants
- carnivores – eat other animals
- omnivores – eat both plants and animals.

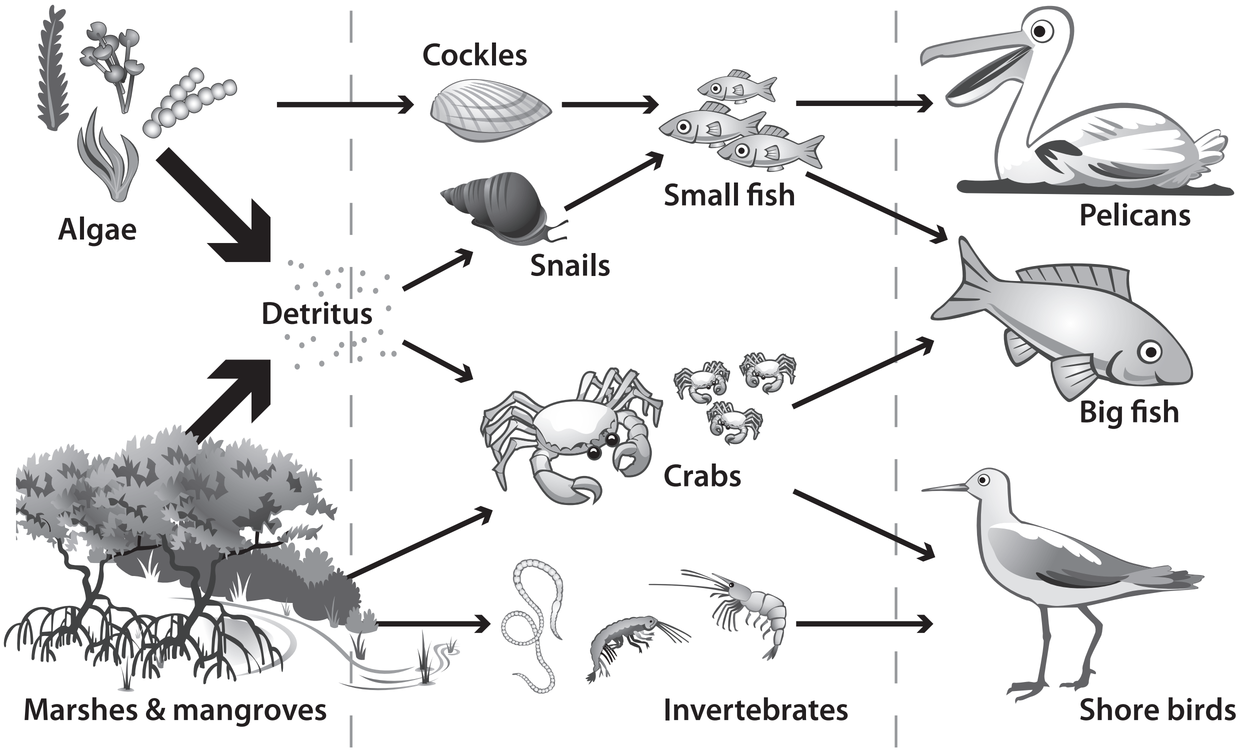
Decomposers

When an organism dies, it is broken down by decomposers such as fungi and bacteria. This releases nutrients back into the environment to be used again by primary producers.

Detritivores

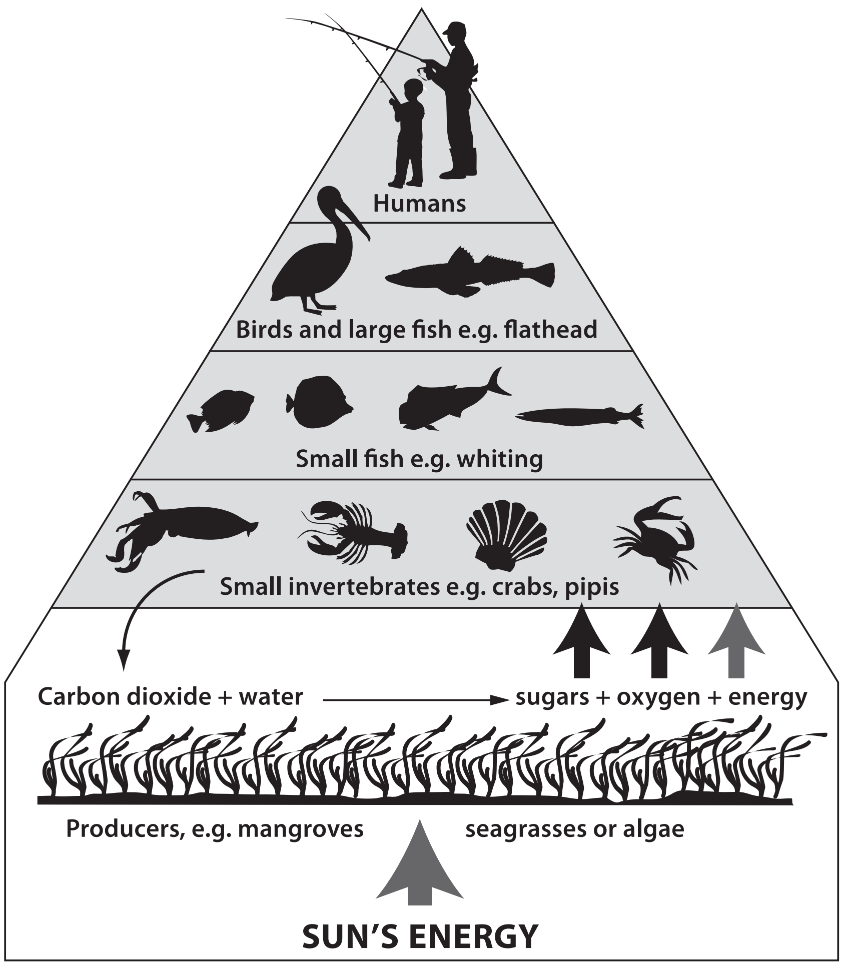
Decaying plant and animal matter is called detritus. Many animals are adapted to feeding on detritus, such as shore crabs and many worms.

Complex food web



Estuary biomass pyramid

Energy from the sun is trapped by plants and transferred to other organisms. At each trophic level, some energy is lost through respiration. As a result, there is a reduction in biomass (living matter) at each trophic level. This reduction in biomass can be represented by a **biomass pyramid**.



An estuary biomass pyramid

SECTION 4

Saltwater bugs

Estuaries, streams, rivers, wetlands and lakes are home to many small animals without a backbone, called invertebrates. They include crustaceans, molluscs and worms. In estuaries these bugs are often called benthic invertebrates. This means they live in or on the estuary floor.

Benthic macroinvertebrates are often used to help identify the ecological impacts of pollutant discharges, or for assessing changes in habitat due to hydrological alterations. The presence and abundance of species adapted to different saltwater habitats provides an indication of the health of the ecosystem.

This section provides information about saltwater bugs to provide background for investigations in the Waterwatch Estuary Field Manual.

Included in this section: *Page*

When investigating saltwater bugs, contact the Department of Industry and Investment (DII) beforehand to check what is allowed in your region and whether or not you need a permit. For studies to produce useful data, it is important for the group to be trained in sample collection and methods of identification.

4.1 What is an invertebrate?

Estuaries, streams, rivers, wetlands and lakes are home to many small animals called invertebrates. Invertebrates have no backbone. This group of animals includes crustaceans, molluscs and worms. In estuaries these bugs are often called **benthic invertebrates.** This means they live in or on the estuary floor.

Macroinvertebrates although small, are large enough to identify with the human eye. Most of the small animals found in and on muddy shores fit into this classification. It includes bugs that live in or on the surface of the mud, from bloodworms to pipis. It does not include living things with backbones, such as small fish.

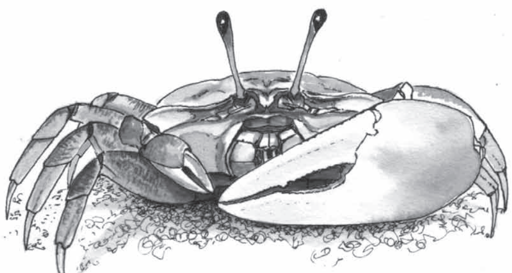
Invertebrates live in the water for all or part of their lives, so their survival is directly related to the water quality. They are a significant part of the food chain, as larger animals such as fish and birds rely on them as a food source.

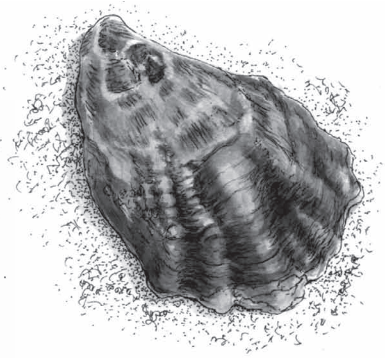
Benthic macroinvertebrates are often found and sampled in intertidal soft-sediment estuarine habitats as well as by the traditional method of netting. They are regularly used to help identify ecological impacts of pollutant discharges, or for assessing changes in habitat due to hydrological alterations.

All water bugs are sensitive to different chemical and physical conditions. The presence and abundance of species adapted to different saltwater habitats provides an indication of the health of the ecosystem. For example, an abundance of some species such as polychaete worms, with a low diversity of other types, may indicate a degraded ecosystem.

4.2 Habitats and bug types

Estuarine habitat types	Macroinvertebrates
Seagrass	Whelks, cockles, shrimp, periwinkles, crabs, snails, amphipods, polychaetes (worms) and squirt worms
Mudflats	
Saltmarsh	Crabs, nudibranchs, mosquito and midge larvae, isopods
Mangroves	Crabs, amphipods, isopods, prawns, shrimp, oysters, oyster borer, whelks, polychaetes (worms), barnacles, mussels
Freshwater river	Freshwater species – see www.bugsurvey.nsw.gov.au

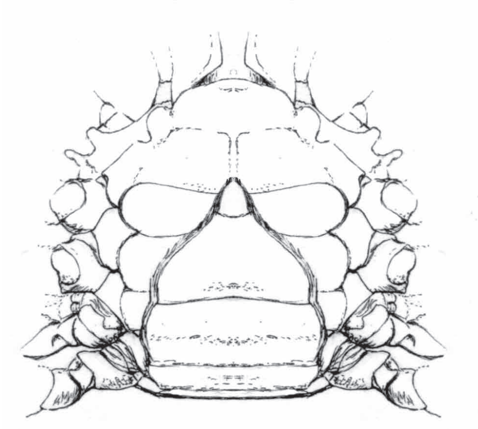




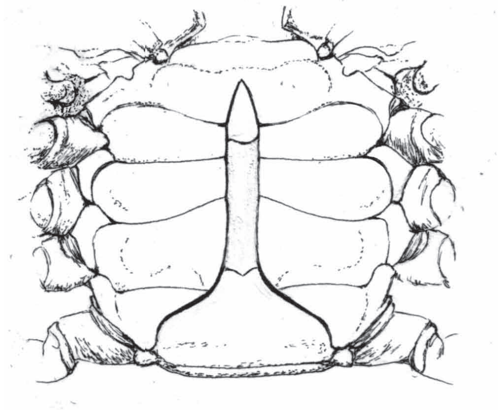
4.3 Life cycle of a mud crab

Some crab species use the estuary's low energy shoreline as a nursery.

The male crab produces sperm which fertilise a female's eggs. Crabs have a hard outer skeleton (exoskeleton). When the female has just shed her shell and her new shell is still soft, the male produces a sperm packet which he deposits under one of her legs connecting to her egg pouch. The female then swims out to sea and releases her eggs with her partner's sperm into the plankton. The eggs are fertilised and quickly grow into a larval stage call zoea.



Female crab abdomen



Male crab abdomen

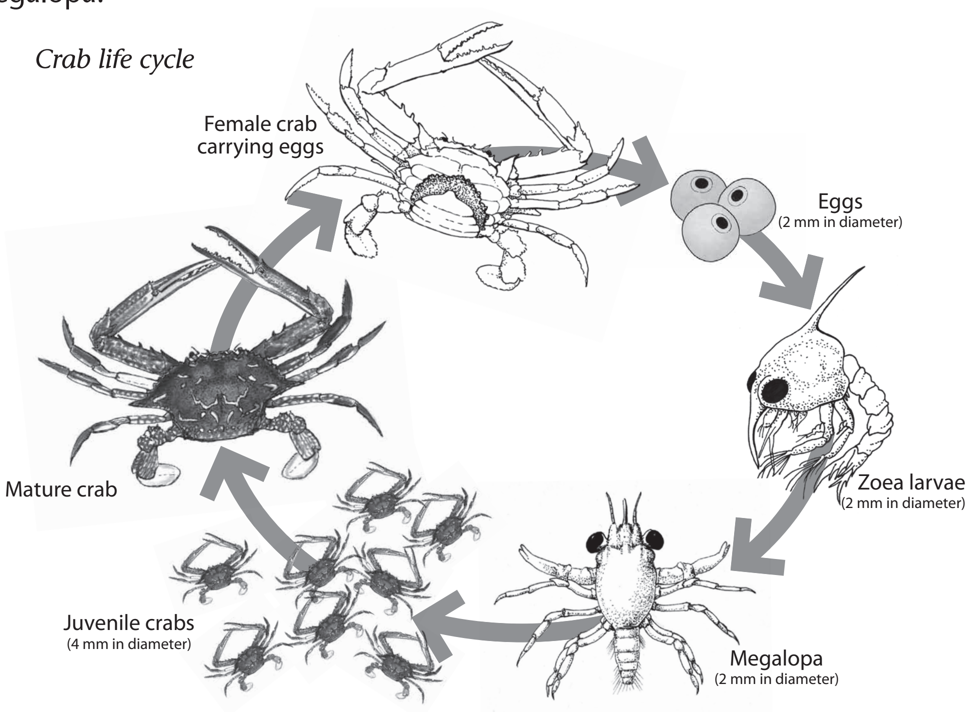
Male and female crabs can be identified by the shape of their abdomen. The female crab carries her eggs in a wide oval flap under her body. The male crab has a V shaped flap.

Crab larvae undergo several changes as they drift back towards the mangroves or saltmarshes where they settle out of the plankton and take on the form of tiny crabs. When they grow large claws they are called megalopa.

The crablets grow quickly because there is plenty of food and lots of protection within the estuary.

The crabs grow into mature adults over a period of two years and make burrows in the nursery areas to find a mate and start the cycle again.

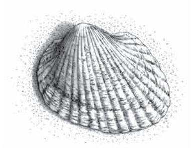
Crab life cycle



4.4 Features of common estuary species

MOLLUSCS	**Molluscs have soft unsegmented bodies usually protected by a shell. All molluscs have a radula – a rasp in their mouth for scraping, piercing, tearing or cutting**			
Gastropods	**Diet**	Most carnivorous or shredders; prey on molluscs, worms and barnacles		
	Movement	Crawling; attach using suction caps		
	Distribution	**Habitat**	**Features**	
Snails 15–30 mm	SE Australia & southern areas	Estuarine mudflats, mangroves	Soft foot, gills and 2 tentacles	
Whelks 20–30 mm 120–150 mm: depends on sp.	SE Australia & southern areas: mud whelk and mulberry whelk	Estuarine mudflats, mangrove swamps	Elongated shell, carnivorous Common spp. hercules club and mud whelk. Grey, brown or white in colour	
Gastropod egg sac	Estuary and low tide zone	Low tide level	A sausage shaped jelly which contains fertilised eggs and larvae	
Nudibranchs (naked gills)	**Diet**	Mostly carnivorous feeding on barnacles, worms and other molluscs		
	Movement	Crawl quickly or 'swim' by contracting body wall muscles to escape predators		
	Distribution	**Habitat**	**Features**	
Sea slugs 10–40 mm	Northern NSW	Mangroves, intertidal	Retreats to holes when tides go out, eyes on back, in groups of 2–3	
Cephalopods ('head foot')	**Diet**	Molluscs, crustaceans, fish		
	Movement	Jet propulsion – contracting muscles to move water in and out, which pushes them forward		
	Distribution	**Habitat**	**Features**	
Cuttle fish 40 cm	Southern NSW coast and southern Australia	Shallow coastal waters & estuaries	Body built around a curved internal bone, can change body colour	
Squid	Qld–NSW border to SA.	Shallow coastal waters & estuaries	Tentacles with clubs on the end, suckers to capture prey	
Octopus 40–60 cm	Southern WA to southern Queensland and southern Tasmania	Shallow coastal waters & estuaries; sandy beds	Can rapidly change their body shape and colour, squirt blue ink into the water to escape	

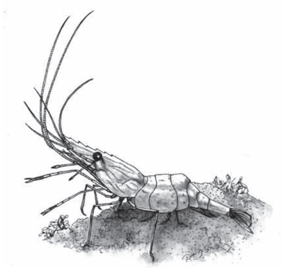
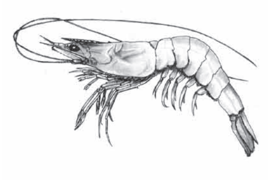
Molluscs (cont.)



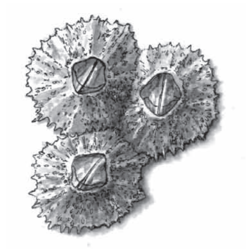


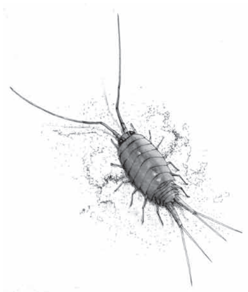
Bivalves	**Many sessile – attached to rocks or roots of mangroves; filter feeders; some burrow**		
Cockles 50–80mm	Southern NSW and Australia	At low water mark and below	Obtain food by pumping sediment in and out with long siphons
Mussels 50–120 mm (edible) 15–30 mm (horse)	NSW to south–west WA	Sheltered and moderately exposed rocky shores, reef and wood pylons	Broad thin wedge-shaped, purplish brown with a shine Horse mussel mostly found on jetties
Oysters 100–180 mm	Mud oyster – southern NSW to WA Other species occur along east coast	Mangroves, mud	Attach to rocks and mangrove roots, outside grey – inside smooth white
Pipis 40–60 mm	Southern Queensland to NSW and South Australia	Sandy shores	Common on beaches – siphons poke out of sand for breathing
Razor shell 400–500 mm	Widely distributed except south–west WA & Tasmania	Soft muddy bottoms in fairly still water	Purple or brown with sharp ribs

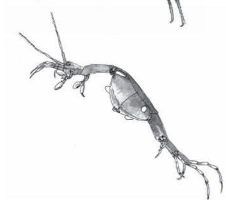
CRUSTACEANS	**Hard-shelled invertebrates with several pairs of jointed legs, a hard protective outer shell, two pairs of antennae, and eyes at the ends of stalks**		
Shrimp	**Diet**	Scavengers – eat detritus – decaying plant and animal matter	
	Movement	Swimming, hopping, jumping	
	Distribution	**Habitat**	**Features**
Estuary shrimp (‘nippers’) 45 mm	Estuaries Australia wide	Estuaries, rivers and lakes with low salinities, in shallow water or vegetated areas such as reed beds	Translucent in colour making them difficult to see in the water column
Prawns 190 mm	Sandy bottom rivers & estuaries from WA, to northern Australia to southern Vic	Soft sediment in lower estuarine reaches	Only young found in estuaries – go to sea to mature Pale green or brown with small green or brown spots

Crustaceans (cont.)

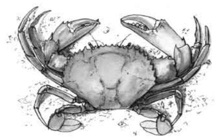
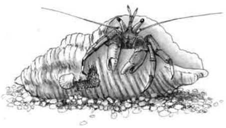
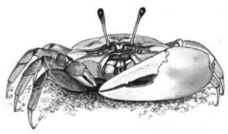
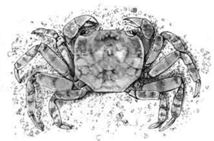
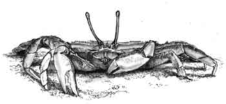
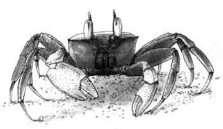


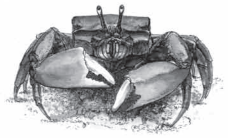
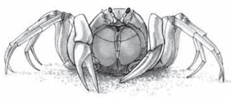


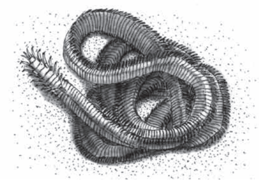
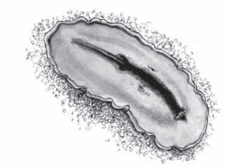


Barnacles	**Diet**	Filter feeder; plankton	
	Movement	Sessile: attached to rocks, jetties, roots of mangroves, depending on species	
	Distribution	**Habitat**	**Features**
Size determined by species: 5–8 mm and 16–18 mm	NSW to north–east Tasmania	May be found on roots and trunks of mangroves but some species will only be found on rocks	White to grey, neither male nor female varieties
Isopods	**Diet**	Most are herbivores or detritivores or scavenge on plant and animal matter	
	Form and movement	Flat bodies compressed from above, crawl or swim, sometimes upside down	
	Distribution	**Habitat**	**Features**
Marine slater 10–15 mm	NSW to southern WA	Estuaries	Slate grey, large head, 2 eyes and 2 large antennae, can be found in huge numbers
Pill bug Most less than 15 mm	Australia wide	Intertidal sandy shores and seagrass beds	Colours vary from to mottled greens and browns to white and cream, rolls itself into a ball for protection
Amphipods	**Diet**	Scavengers; on plant and animal detritus or bacteria on the surface of sediment particles	
	Form	Narrow body compressed at sides – translucent, brown or grey and some are green, red or blue-green in colour	
	Distribution	**Habitat**	**Features**
Sand hopper 6–20 mm	Australia wide	Intertidal mud/ sand	Jump and hop
Skeleton shrimp Mostly 20 mm	Australia wide	Usually attached to seagrass and algae	Moves in loops – crawls through seaweed and is camouflaged to match the seaweed in which it lives

Crustaceans (cont.)

Crabs	**Diet**	Carnivorous – snails, mussels and other small invertebrates; decaying matter, swimmer crabs may eat seagrass	
	Form	Burrowing, swimming; crabs moult their shell – expand new soft shell by filling it with water, it then hardens to a larger shell	
	Distribution	**Habitat**	**Features**
 **Mud** >240 mm	Mid Queensland coast to SA	Shallow water with soft bottom esp. near mangroves	Deep green or green brown mottled crab
 **Blue swimming** 300 mm	Mid WA coast to NSW coast to Bega	Sheltered bays and inlets and estuaries, burrows into mud	A broadly flattened last pair of legs that enables them to swim, and a flattened carapace that usually bears spines along its sides
 **Hermit** 80–150 mm	Southern Australia	Intertidal flats near mangroves	Long, soft, coiled abdomen which is usually hidden inside a discarded shell or sometimes a rock, tumbles about with borrowed shell One species characterised by having the left claw longer or the same size as the right claw
 **Fiddler** 2 main species 15–20 mm	Northern Australia to Sydney NSW	Sand and mud flats and near mangroves in sheltered bays, creeks and river mouths	Eyes on stalks to look out of their burrows Female 2 small claws, male has one enlarged claw
 **Smooth shore crabs** 30–40 mm	Mid Queensland coast to SW WA	Estuaries and mangroves	Purple, dark grey or purplish grey, scavenger eats whatever is around
 **Spotted mottled shore** 30–35mm	Southern Queensland to northern Tasmania	Sheltered bays and estuaries in mud areas and saltmarsh flats	Very large purple-brown and red claws and grey or yellow flecked carapace
 **Sentinel** 30–40 mm	Northern Australia and Queensland to Sydney NSW	Mangroves and mudflats and seagrass areas	Territorial and defends burrows, two species, one dominating seagrass and the other buries itself in soft mud, drab green and light brown colour
 **Ghost** 35–50 mm	Northern Australia to mid north coast NSW	Dry sand near estuary entrance or sandy estuarine beaches	Light grey in colour, rounded shell, large eyes at the end of short eyestalks

	**Smooth handed** 25–30 mm	Southern Queensland to WA	Seagrass, tidal flats and rock and wood structures	Purple colour and hairy covering on its legs
	**Semaphore** 20–25 mm	Southern Queensland to northern Tasmania	Estuaries where there are soft but stable mudflats	Mottled purple, white claws and long eyestalks, males ‘waving’ are distinctive
	**Red fingered** 20–30 mm	Central Queensland to southern NSW	Mangroves, estuaries, saltmarsh and on river banks	Square shaped carapace, greenish black with fingers red
	**Soldier** 12–15 mm	WA to Queensland and NSW to Victoria and Tasmania	Estuaries sand/ mud	Burrows into sand in corkscrew manner if frightened

WORMS	**Polychaetes**	**Diet**	Tubeworms are filter feeders and ingest small particles of organic matter from the water column. The worms collect plankton in their tentacles. Beach worms eat dead fish, seaweed, dead octopuses and pipis	
		Form	Some live in tubes while others are free moving and burrow into the sand and mud	
		Distribution	**Habitat**	**Features**
Annelida (segmented worms)	**Rag worm** 60–120 mm	Widely distributed	Sand, mudflats and seagrass	Rag worms are commonly brown, bright red or bright green
	**Tube worm** 30–50 mm	Southern Australia	Intertidal flats	Build tubes, often cemented together, in which to live
	Unsegmented worms	**Diet**	Carnivorous, eating small invertebrates	
		Movement	Slide over rocks but can also swim	
		Distribution	**Habitat**	**Features**
Platy - helminthes 	**Flat worm** 1–10 mm	Southern Australia	Mudflats, estuaries	Flat and leaf-shaped, very thin, flexible and almost transparent. The mouth is in the middle of the underside of the body. They eat dead animals or capture small invertebrates alive by wrapping themselves around their prey and entangling it in slime
Nemerteans 	**Ribbon worms** Orange – 50 mm Brown – 300 mm	Southern Australia	Estuary waters and mudflats	Carnivorous with a long proboscis which is either sticky or has poisonous hooks to capture prey

SECTION 5

Human impacts on estuaries

The human use of catchments has modified the natural environment. This has changed both the quality of our water, and the way that water flows (quantity), with large effects on our native vegetation, animal life and soils. Human impacts upstream have a flow-on effect downstream in estuaries.

Most of the Australian population lives on or near the coast. This means that most people live near an estuary. The continuous urbanisation and development of our coastal environments directly affects the health of our estuaries. Everything that happens in the catchment ends up in the estuary, eventually.

This section contains information about human impacts and how they affect the health of estuaries. Ideas for actions to protect estuary environments are also provided.

Included in this section: *Page*

5.1 Summary of human impacts

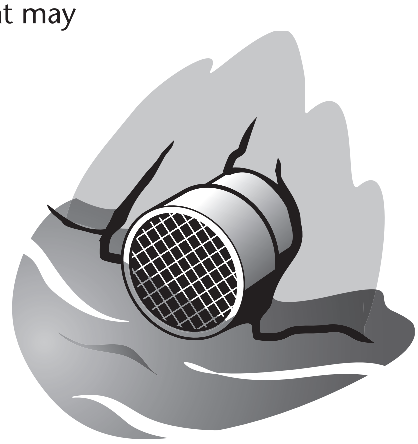
- **Clearing of riparian vegetation** for tourism, urban and agricultural purposes degrades estuaries. Use of this habitat type by humans and livestock has led to bank erosion, soil compaction and the lack of regeneration of plant zones. Disturbance due to clearing has allowed the infiltration of pest and weed species.
- **Structures** such as sea walls, bridges, drains, jetties, marinas, levy banks, rock walls, and breakwaters all affect the passage of water and can alter the conditions within an estuary.
- **Urban development, agriculture** and **grazing** can all increase erosion that causes sediment and nutrient loss to estuaries. This may smother seagrass which is key habitat for food production and a nursery area for fish.
- **Seagrass wrack putrification** is usually caused by a man-made object that traps seagrass blades and stops them from dispersing naturally. This causes putrification which can cause odour problems. Some of these man-made traps are inappropriate dredging, works, moorings of the fore and aft pole variety, sea walls, groynes, marinas and jetties.
- **Insects** breed in the wetland areas, saltmarshes and tidal fringes of an estuary and are an important component of a healthy and balanced estuarine ecosystem. Often there is pressure on the local council to eliminate or reduce insect nuisance by filling or draining breeding areas, or by use of pesticides. All of these activities have adverse effects on the estuarine environment.

5.2 Litter

Litter on our beaches and floating in Australian marine and estuarine waters is a problem, particularly non-biodegradable litter. It tangles in the appendages of our marine life and is harmful to divers and beach users. Some of the effects of different types of litter are:

- **Soft drink rings** may trap seabirds.
- **Plastic bag**s may be eaten by sea turtles, mammals or entangle fish.
- **Sharp needles** and **bits of glass** give nasty cuts or diseases to beach users.

- Bits of **net** entrap anything from humans, to marine mammals or fish.
- Cans of **propellant** and **heavy oils** can cause mini oil spills that may kill significant colonies of barnacles or other marine life.
- **Cigarette butts** can make fish sick.
- Australian beaches are some of the best in the world, and large amounts of **beach litter** causes them to look unsightly. This detracts from tourism which is a multi-billion dollar industry in Australia.



5.3 Urban development

- **Tidal barriers** such as weirs and floodgates eventually convert upstream reaches from a brackish to a freshwater environment. In addition, these barriers impede or prevent the movement of fish and prawns and can lead to prolific weed growth upstream of the barriers. These days, the appropriate design of new works can preserve existing wetland areas whilst providing flood protection.
- **Sewage** outfalls and septic overflows contribute excessive nutrient levels and biological pollutants that may be harmful to human and aquatic health. High levels of nutrients can lead to algal blooms, potentially toxic, or excessive growth of aquatic plant life which then dies off, causing a loss of dissolved oxygen and rotten odours.

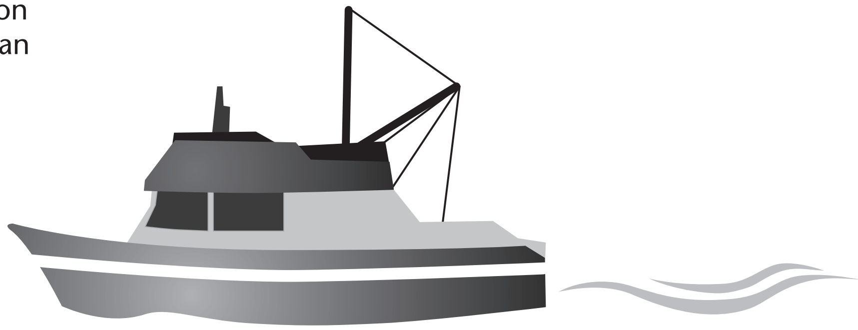
5.4 Agricultural

- **Erosion** and subsequent transport of sediment into waterways and estuaries has a highly detrimental effect on estuary health. Sediment build-up affects flow and flushing of estuaries; high levels of turbidity smother seagrass beds and other aquatic vegetation and this reduces habitat and food sources.
- **Dams** and **weirs** impact on estuaries by changing the pattern of flow. This may affect the flushing of coastal streams and increases the area of saltwater intrusion. Flood mitigation works also impact on flow patterns in coastal areas.
- **Dams** and **power stations** can both affect ecosystems by changing the temperature within aquatic ecosystems. Cold water from dams and warm water from power stations are forms of thermal pollution that affect waterways.

- **Agricultural fertiliser** runoff can affect the health of estuaries, especially the use of superphosphate which can increase phosphate levels in an estuary, which in turn can stimulate algal blooms. Toxic algae species (e.g. blue-green – *Nodularia*) are often best able to take advantage of an increase in phosphate in estuarine waters and can cause death of livestock, domestic pets and small children, if consumed.

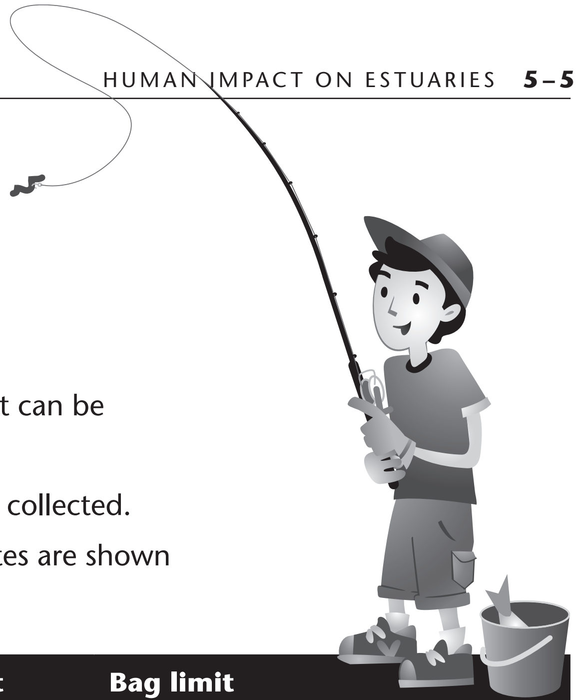
5.5 Boating

- **Boat wakes** can be very damaging to riverbanks, especially large wakes at high tide. Bank collapse and complete loss of mature, old habitat trees has been noted in several NSW estuaries.
- **Dredging** for improved boat passage and safety can result in the exposure to the atmosphere of acid sulphate soils. This runoff can severely affect estuarine water quality for short periods of time (if the runoff drains to an estuary). The rapid drop in pH can result in a fish kill. If properly controlled, dredging–based extractive operations can also benefit an estuary by increasing tidal exchange, enhancing water circulation, facilitating navigation and creating new wildlife habitat; however dredging changes the flow of water and can affect the whole ecosystem.
- **Anchoring** in seagrass beds damages and kills the seagrass and some species (e.g. *Posidonia*) can take up to 100 years to recover.
- **Propeller damage** to seagrass beds and other estuarine aquatic vegetation has a major effect on estuary health, reducing or degrading habitat and disrupting the food chain.
- **Jetties** and any form of construction that protrudes out into the water can change the flow within an estuary and cause a loss of foreshore habitat; however, jetties also create habitat for shellfish and shelter for small fish.



5.6 Industry

- **Over-fishing** and habitat loss reduces fish stocks and disrupts the food chain.
- **Trawling**, commercial shipping, recreational boating and dredging can have a significant impact on benthic communities (bottom dwelling organisms) and may also disturb the roosting and feeding patterns of birds.
- **Sand and gravel extraction** also has a significant effect on benthic communities and can cause turbidity, which affects seagrass health and the food chain in an estuary. Migrating and nesting birds may also be disturbed.
- Construction of **rock walls** to stabilise an estuary entrance, and oyster farming, can alter the ebb and flow current patterns within an estuary and cause a loss of foreshore habitat. The oyster farming industry is reducing this impact by realigning oyster racks to promote flushing of the lease areas.
- **Prawn and fish farms** have the capacity to pollute estuary areas by returning flows from their breeding ponds back to the estuary. These can have very high concentrations of organic matter and other pollutants, as prawns and fish are fed with high nutrient food pellets, and their defecation also fouls the water.



Saltwater bag and size limits

There are rules about the number and size of macroinvertebrates and fish that can be caught on any visit to an estuary.

Bag limits: the number of animals of each species that can be collected per fisher.

Size limits: the minimum size of a species that can be collected.

Bag and size restrictions related to saltwater invertebrates are shown in the table below:

Macroinvertebrate species	Size limit	Bag limit
Beach worms		20 whole or in part
All other worms		100 in total*
Cockles, mussels (pipis for bait only)		50 in total*
Blue swimmer crabs	6 cm	20
Crabs (mud and black mangrove)	8.5 cm	5
Crabs – all others except soldier		10 in total
Crabs (soldier)		100 in total*
Oysters		50 in total*
Prawns		10 litres in total*
Saltwater pink pippers		100 in total*
Scallops		50 in total*
Squid and cuttlefish		20 in total*
Turban snails	Sydney military 7.5 cm	
All other molluscs		20 in total including turban shells
Fish species		
Flathead – dusky/common	36 cm, only 1 over 70 cm	10
Flathead – sand	33 cm	20 in total*
Flathead – tiger		20 in total*
Leatherjackets		20 in total*
Mangrove jack		5
Mullet – small (poddy)	<15 cm	20 in total*, for live bait only
Mullet – sea (bully)	30 cm	20
Whiting	Sand only, 27cm	20 in total*

* Bag limit composed of a single species or a combination of listed groups of species.

Source: NSW Department of Industry and Investment, 2009

5.7 Climate change

Climate change is one of the most significant impacts of human use of our environment. Predictions about how climate change will affect estuaries in New South Wales include higher air and sea temperatures, sea level rise, more extreme storms, less rainfall with most falling in storm events, and more flooding. As one third of Australians live near the coast, climate change will impact on many communities.

Projected impacts of climate change 2050

1. Sea level rise – It is predicted that by 2050 sea levels will rise by 40 cm from the 1990 level and 90 cm by 2100. 'The higher sea levels will move the tidal and salinity limits inland. This could expose new areas to salt and brackish water and affect terrestrial flora and fauna and aquatic life. In addition, the changes would interfere with present land use practices, e.g. the use of low lying land for farming purposes.' (NSW Government, *NSW Coastline management manual*, 2009).

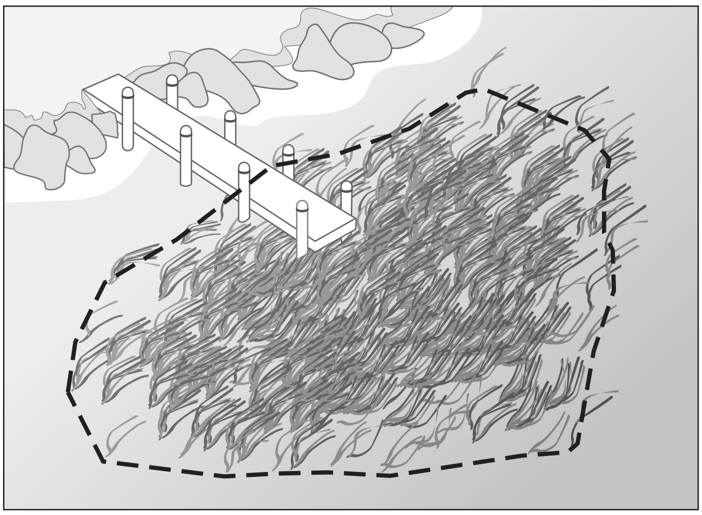
2. Temperature rise – It is predicted that temperatures will increase and that mean maximum temperatures will rise 2–3 degrees by 2050. As daily temperatures rise, seas will expand and marine influences in estuaries will increase. There will be a higher mean tide and a higher degree of flooding due to storms and sea surges throughout the estuaries of New South Wales. This will increase coastal erosion and flooding.

3. Increased summer rainfall – It is predicted that rainfall will increase by 20–50% in summer with 10–50% less rainfall in winter.

4. Reduced water quality - As temperatures rise, water becomes less able to hold dissolved oxygen. Increased frequency of higher intensity storm events will produce greater sediment and nutrient loads. As a result, estuary water quality and overall health is very likely to decline.

5. Seagrass beds – These will potentially increase in size due to the change of water levels and greater availability of sunlight; however, if turbidity levels rise due to erosion and coastal storm activity these benefits may be reduced.

Waterwatch groups can help to track the effect of climate change by monitoring water and air temperature, plus turbidity, dissolved oxygen and nutrients, particularly in storm events. Mapping seagrass beds and determining seagrass condition is also helpful. It is also predicted that mangroves will increase in area and saltmarsh will decrease as temperatures increase. Mapping of all habitat types in an estuary will assist with tracking the effects of climate change.



Monitoring seagrass can provide useful information about the impact of climate change. Procedures for Waterwatch groups are contained in the Estuary Field Manual.

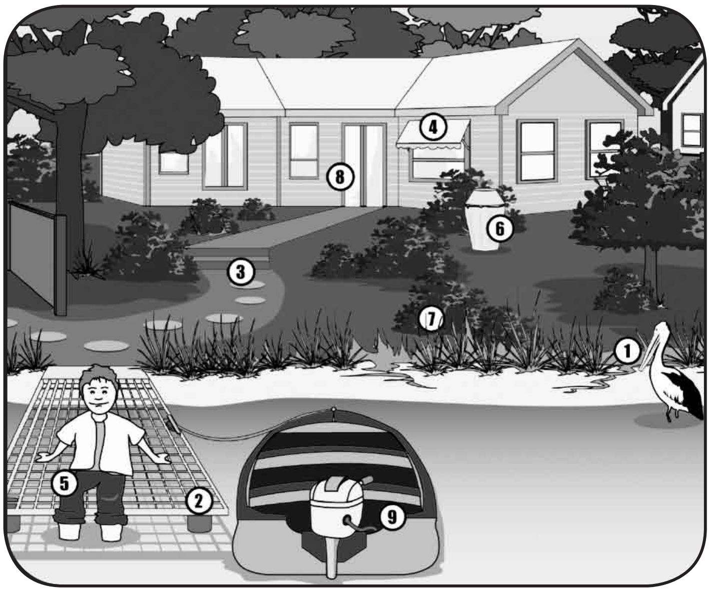
5.8 Protecting our estuaries and foreshores

Be a foreshore friend!

- When fishing, take bait bags and tackle home. Fishing tackle can entangle wildlife and plastic bait bags can end up in the estuary, causing the death of aquatic species.
- Make sure you have a fishing licence and that you observe the bag limits for particular species.
- Plant local native species in your waterfront buffer and garden and avoid plants that can 'escape' into bushland.
- Restore a natural slope to your water frontage and ensure access around the foreshore.
- Help protect and rehabilitate foreshore bushland by getting involved in Landcare.
- Leave dead and fallen trees to provide wildlife habitat.
- Compost your grass clippings and garden waste and keep them away from foreshore reserves.
- Launch boats only from properly constructed and authorised boat ramps and store boats within your property.
- Leave dead seagrass along the foreshore beach to reduce erosion and provide habitat.
- Keep vehicles off foreshore reserves to avoid environmental damage.
- Remove unauthorised structures, and ensure authorised structures are designed and maintained to reduce environmental impacts.

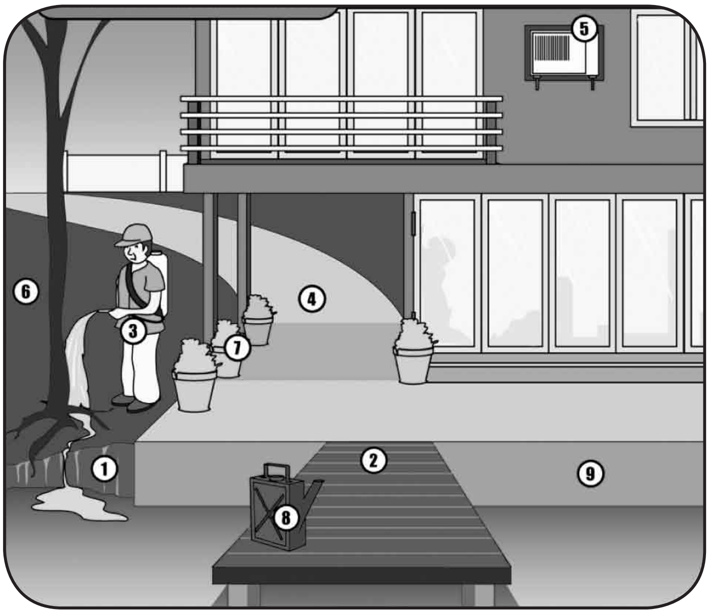
Source: *"Living on the edge"*, Lake Macquarie City Council, 2005.

Low impact development and lifestyle



1. Natural sloping shoreline – allows dead sea grass to wash out, improving water quality.
2. Small shared jetty with open mesh deck – low impact on 'ribbon of life'.
3. Stepping stones for footpath – less chance of water runoff and erosion.
4. Trimmed trees and adjustable awnings – natural air conditioning with view maintained.
5. Work less – relax more!
6. Kitchen compost – improves your soil's quality.
7. Low maintenance native plants for stabilisation and filtration – provides shoreline buffer.
8. Building – set back from shore and in character with setting.
9. Well maintained motor – electric or modern 4-stroke outboard, operated with low wake near shore.

Greater impact development and lifestyle



1. Bare shoreline – subject to erosion.
2. Solid deck on jetty – affects sea life habitat.
3. Fertiliser spills and chemical runoff from lawn damages water quality.
4. Paved driveways – pollution-laden runoff flows to water.
5. No shade trees – over-worked air conditioner adds to your electricity bill.
6. Removal of natural vegetation – more work for you and more runoff.
7. Ornamental shrubs – require chemicals and extra work!
8. Poor fuel management – spills are deadly!
9. Hardened seawall shoreline – eliminates 'natural filter', degrades water quality and causes erosion elsewhere.

Source: *Living on the Edge*, Lake Macquarie City Council, 2005.

5.9 Ideas for improving your waterway

Once you have conducted a range of assessments at the waterway, you can decide what your class or community group can do to improve your local water quality. Here are some ideas which may help you:

- Identify the main problems at the site.
- Make up a list and put the most important things first.
- Is the problem something the class can help with or will you need to notify the Catchment Management Authority (CMA), council or Landcare group?
- Can you assist another group with these actions?

Actions now!

Some things can be done straight away. Here are some ideas:

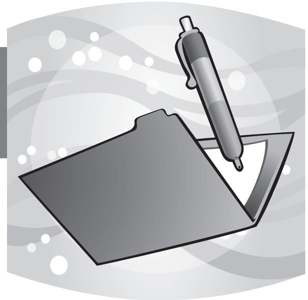
- Monitor the water quality regularly and contribute data to the NSW Waterwatch online database. This will provide catchment managers with information about the health of your site.
- Clean up rubbish, ensuring you do this safely, with gloves and a pole if possible.
- Invite local newspapers to report your water monitoring results.
- Write articles to the local newspaper about the value of the waterway and its plant and animal life.
- Make a display for your school or the local shopping centre.
- Put up a poster at your local shop to update the community each time you monitor.
- Contact other people who can help.
- Put together a PowerPoint presentation for informing your school, community groups, CMA and local government.

Longer-term objectives

This may involve working with other groups in the community, e.g. Landcare groups or councils. With these groups you could:

- Grow trees to plant at the waterway and/or plant trees to prevent erosion of creek banks.
- Put your data into your local newsletter to alert your community to any changes.
- Help remove weeds.

SECTION 6

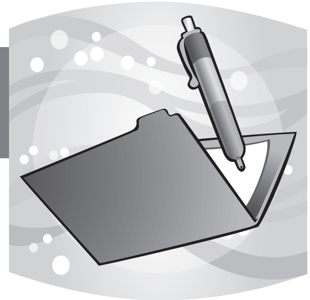


Glossary

abundance	presence of an organism recorded in numbers
anaerobic	living or occurring in the absence of oxygen
anoxic	describes a condition where oxygen in an estuary has been completely used up by microbial activity
area	the area of an estuary is the area below the mean high tide mark between the mouth of the estuary and its head
benthic	associated with the bottom, or sediments, of an estuary
biodiversity	the variety of all plants, animals and micro–organisms in an ecosystem, biome or the entire earth
biota	includes all living organisms in a given habitat or area
brackish	describes water with a low salinity concentration, i.e. in between seawater and freshwater
chlorophyll	green pigment in plants that enables them to use the energy of the sun for photosynthesis
detritus	decaying plant and animal matter
detritivores	organisms that break down dead matter
dynamic	unstable, continuously changing
ecological health	the state or condition of an ecosystem in relation to a desired outcome
epiphytic growth	a brown slimy growth often found on seagrass
ephemeral	temporary, existing for a limited time only
estuary	a partly enclosed body of water where a river meets the sea
eutrophication	the build up of nutrient levels in an estuary, leading to excessive growth of aquatic plants which, in turn, depletes oxygen levels within the estuary
fluctuations	changes or variations
hypersaline	having a salinity greater than that of seawater, i.e. above 35 parts per thousand
ICOLLS	intermittently closing and opening lakes and lagoons where the estuary may be sealed off or isolated for long periods of time
intertidal	describes the area between the high and low tide marks

macrophyte (algae)	rooted aquatic plants, e.g. seagrass, or large attached algae of several types, e.g. red, brown or green
mangroves	plants adapted to saline conditions that grow in soft sediments within the intertidal zone
mouth	the area of the estuary where the salinity is indistinguishable from that of seawater
organic	describes material derived from living, or once living, organisms
phytoplankton	microscopic or small organisms in the water column with the ability to photosynthesise
photosynthesis	the process by which sunlight is harvested and used to convert carbon dioxide and water to carbohydrates
quadrat	an object with a fixed area used for sampling; may be square, rectangular or circular
plankton	microscopic organisms that drift freely in the water and can have both animal and single celled plant components
respiration	gas exchange (oxygen and carbon dioxide) by organisms
runoff	rainfall that drains off the land's surface
saline	water that contains salts at various concentrations
salinity	the total mass of dissolved salts per unit mass of water; the salinity of seawater is approximately 35 parts per thousand or 35 grams per kilogram
saltmarsh	plant communities that are flooded with water during high tide and consist mainly of herbs, sedges, grasses and low shrubs
seagrass	a flowering plant that lives in marine and brackish water
seagrass wrack	the shed or detached leaf material of seagrass plants
secchi disk	a circular disk marked with black and white quarters used to measure water clarity
species composition	the collection of species which make up a particular community
species richness	the number of different species within a community
stratification	a separation of the water column whereby denser waters lie underneath less dense surface waters, usually associated with changes in salinity or temperature
terrestrial	land based
tide	the movement of water due to the gravitational pull of the moon and the sun
transect	a line or belt used to survey the distributions of organisms across a given area

SECTION 7



Bibliography

Australian and New Zealand Environment and Conservation Council 1992, *Australian water quality guidelines for fresh and marine waters,* National Water Quality Management Strategy, ANZECC, Canberra.

Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand 2000, *Australian and New Zealand guidelines for fresh and marine water quality,* ANZECC & ARMCANZ, Canberra.

Community Environment Network, Ourimbah, *'Seagrass monitoring manual',* unpublished.

Coleman, P and Cook, F 2003, *Waterwatch South Australia guidance manual: estuarine monitoring,* Delta Environmental Consulting, St Kilda, South Australia.

Davey, K 1998, *A photographic guide to seashore life of Australia,* New Holland Publishers, Sydney.

Department of Primary Industries Queensland, Northern Fisheries Centre, McKenzie, LJ, Campbell, SJ & Roder, CA 2001, *Seagrass-watch,* Global seagrass monitoring network, accessed July 2009, www.seagrassNet.org.

Department of Environment Western Australia 2005, *A field guide to common estuarine invertebrates of Southwestern Australia,* Ribbons of Blue, Waterwatch WA.

Department of Environment, Climate Change and Water 2009, *NSW sea level rise policy statement,* NSW Department of Environment, Climate Change and Water, Sydney.

Edgar, GJ 1997, *Australian marine life: the plants and animals of temperate waters*, New Holland Publishers, Sydney.

Hawkesbury–Nepean Catchment Management Authority, *Sustaining our salt marshes,* Hawkesbury–Nepean CMA fact sheet, available at www.hn.cma.nsw.gov.au/multiversions/4090/FileName/the%20source%20Insert7.pdf.

Lake Macquarie City Council 2005, *Living on the edge: a guide for residents in foreshore areas,* Lake Macquarie City Council, available at www.lakemac.com.au/downloads/LivingOntheEdge.pdf.

Maggie's earth adventures 2007, *The teacher's lounge*, accessed July 2009, www.missmaggie.org/eng/teachers_index.html.

NSW Department of Natural Resources 2006, *Estuaries in NSW*, accessed July 2009, www.dnr.nsw.gov.au/estuaries/index.shtml.

NSW Department of Primary Industries 2008, *Prime fact 746: Mangroves*, NSW Department of Primary Industries, Sydney, available at www.dpi.nsw.gov.au/__data/assets/pdf_file/0020/236234/mangroves.pdf.

NSW Department of Primary Industries 2007, *Prime fact 649: Seagrass*, NSW Department of Primary Industries, Sydney, available at www.dpi.nsw.gov.au/__data/assets/pdf_file/0019/203149/seagrasses-primefact-629.pdf.

NSW Department of Primary Industries 2005, *Fishing and aquaculture: Caulerpa (*Caulerpa taxifolia*)*, NSW Department of Primary Industries, Sydney, available at www.dpi.nsw.gov.au/fisheries/pests-diseases/marine-pests/species/caulerpa-taxifolia.

NSW Department of Primary Industries 2005, *Fishing and aquaculture: Estuarine habitats*, NSW Department of Primary Industries, Sydney, available at www.dpi.nsw.gov.au/fisheries/habitat/aquatic-habitats/estuarine#Saltmarsh.

NSW Government, 1990, *NSW coastline management manual.*

Queensland Department of Natural Resources and Mines 2003, *Community estuarine monitoring manual*, Queensland Department of Natural Resources and Mines, Brisbane.

The New Inventors 2007, television program, Australian Broadcasting Corporation, Sydney, 6 June. Video clip of segment about seagrass mooring available at www.abc.net.au/tv/newinventors/txt/s1940114.htm.

Rowley, M 2003, *Estuary monitoring manual draft vol. 1*, NSW Department of Land and Water Conservation, Sydney.

Waterwatch Central Adelaide 2007, *Teaching resource pack: Catchment to coast*, available at www.waterwatchadelaide.net.au/uploads/file/pdfs/coasts_and_estuaries/CatchmenttoCoast(WCA%20updated%20WEB).pdf.

Waterwatch Australia Steering Committee 2007, *Waterwatch Australia national technical manual, Module 7– Estuaries*, Environment Australia, Canberra.

Please note: NSW Department of Primary Industries, Prime Facts, will be available from the Department of Industry and Investment website from 2010.