The vulnerability of coastal and marine habitats in South Australia

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Introduction

South Australia's marine environments are unique and contain some of the most biologically diverse waters in the world enjoyed by many as part of their recreational activities. South Australian waters are also important for South Australia's economy, supporting a wide array of activities from mining and shipping to fishing, aquaculture and tourism. Pollution, invasive species, habitat loss and fragmentation, over-harvesting of species and climate change have been highlighted as key pressures on marine habitats (Marine Biodiversity Decline Working Group 2008) and effective management is needed to protect these environments and their plants and animals from the impacts of increasing pressures. Worldwide, Marine Protected Areas (MPAs) have been proved to be a fundamental management tool to conserve biological diversity, and to maintain ecological integrity and ecosystem resilience.

In 2005, the then South Australian Minister for Environment and Conservation appointed a Scientific Working Group (SWG) to provide independent advice on marine matters, particularly in relation to the design of South Australia's marine parks network. The SWG assisted the Government in the development of a set of outer boundary design principles (DEH 2008), which informed the design of 19 marine parks. In 2009, the South Australian Government proclaimed the marine parks network under the *Marine Parks Act 2007* that includes representative areas of the 8 South Australian marine bioregions, as part of SA's contribution to the National Representative System of Marine Protected Areas.

An understanding of the vulnerability of South Australia's key coastal and marine habitats is important for the design of multiple use marine park zoning, as well as the design of monitoring programs for the marine parks network. To document this understanding, members of the Scientific Working Group, in collaboration with other scientists, have authored this series of technical papers on the vulnerability of thirteen coastal and marine habitats. Each chapter describes the distribution, function, key threats, vulnerability and marine park considerations for that particular habitat. The vulnerability of some habitats, such as rhodolith beds, is not well understood as they are little known and seen by few. Greater knowledge exists for other habitats, such as mangroves and seagrasses.

This series of papers does not provide an exhaustive list of all marine habitats in the State, but it covers most habitats considered critically important by the SWG for conserving within the marine parks network. The papers do not seek to explicitly outline all of the pressures upon marine habitats; rather, to discuss a few key pressures specific to each habitat. As such, this document goes some way towards highlighting the importance and vulnerability of key coastal and marine habitats within South Australia's.

Algal forest habitats

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Description

On South Australian reefs algal forests are habitats dominated by macro-algae. The forests can comprise of up to five different layers or strata as shown in Figure 1. The uppermost stratum is the giant kelp, found only in the South East(SE) of the State (see separate account of *Macrocystis* forests), and below this is the layer of canopy species up to 1 m high, comprising the kelp, *Ecklonia,* and the fucoids, with many species of *Cystophora* and *Sargassum* – all species that are widespread throughout the State.

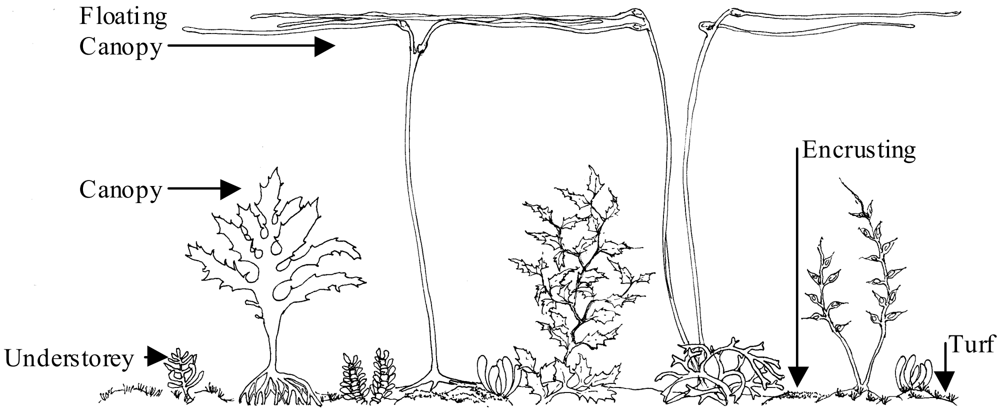

Figure 1.The five layers or strata of a macro-algal assemblage (after Turner & Collings 2008).

The kelp *Ecklonia* tends to dominate exposed coasts, while the fucoids dominate moderately exposed to very sheltered reefs. The fucoids themselves (Order *Fucales*) are extremely rich in species, with some 67 species in southern Australia, the centre of their diversity globally. Their vertical distribution reaches 10 –20 m in depth on coastal reefs, but distribution can be much deeper (to >50 m) on offshore reefs in the clear waters of the eastern Great Australian Bight (GAB).

Below the canopy is the algal understorey of (plants to ~40 cm high) which is extraordinarily rich in species, with ~1 000 or more species recorded within South Australia (SA) alone. Some species are widespread throughout southern Australia, whilst others are rare or with very restricted distributions. Below the lower depth limit of the canopy species red algae extend throughout the deeper photic (light) zone to a depth of 20–30 m on most coastal reefs, but can extend to depths of ~70 m in oceanic waters, such as the SE of SA or the eastern GAB.

Below the main understorey are algal turfs 1–2 cm high and encrusting algae comprising mainly calcified corallines. Algal turfs extend to 20 m depth or more with encrusting algae recorded to >100 m.

The high diversity of canopy and understorey species results in algal forest habitats being heterogeneous to the extreme, with change occurring continuously with shifts in temperature, exposure and other factors along the coast.

Distribution

Algal forest habitats occur on all rocky coasts except those in the upper Gulfs where algae are much less abundant. The SE coasts of South Australia are especially rich, with the large macroalgae, *Macrocystis*, *Phyllospora*, and *Durvillaea* being present.

Function

Productivity

A mixed *Ecklonia*-fucoid habitat at ~4 m depth, showing *Ecklonia* (left) and species of *Sargassum* and *Cystophora*
(Photograph: Alison Eaton).

The productivity of kelps is very high, as shown by the studies of Kirkman (1989) and Fairhead and Cheshire (2004a, b). For example, Kirkman calculated that an *Ecklonia* forest produced 22 times its own fresh weight a year, and this represents only ~11% of the carbon uptake of the kelp – the rest going back into the water as respired carbon, eroded tips of the blades, and in spore release. These in turn enter the food web and help support the innumerable plankton, herbivores and plankton feeders of coastal waters.
The productivity of fucoid algae is also very high. The crayweed, *Phyllospora comosa*, and the bull kelp, *Durvillaea potatorum*, that occurs in the SE of SA, produce 10 or more times their own weight a year (Sanderson 1992; Cheshire and Hallam 1989). The productivity of a mixed algal community at ~4 m depth, comprising mainly species of *Cystophora* and *Sargassum*, together with its understorey species was studied by Cheshire *et al*. (1996). The annual production of this community was estimated to be 19 times its own weight. Algal turfs only 1–2 cm high, which occur patchily in disturbed habitats, are also highly productive, and produce up to 10 times their weight a year (Copertino *et al*. 2005). In deeper water of 12–15 m red algal communities are also very productive, considering the reduction in light, and Shepherd (1979) and Sanderson (1992) found that they produced ~10 times their own weight a year.
Overall, it is evident that temperate reef algal systems are extremely productive in terms of carbon produced, and maintain a rich diversity of animal species, that are dependent on them for food.

Benefits

As described in the separate chapter on *Macrocystis*, kelps and fucoid algal habitats create an environment that supports a rich diversity of plant and animal species. These forests have both physical and biological functions as follows:

- the canopy dampens water movement, and provides a more sheltered habitat beneath it;
- the habitat favours a diverse flora and fauna under, and in patches between, the canopy;
- by its architecture provides micro-habitats in the upper and mid-canopy , and within holdfasts on the substratum;
- recycles nutrients taken up from the water;
- provides an abundant food supply for animals living in and around the forest;
- provides a nursery habitat for juveniles of many fish and other species.

In addition to the above general ecosystem services of the forest system, there are many mutualisms and other specific relationships between species. A good example is the obligate relationship between abalone larvae and crustose corallines. The coralline contains a settlement inducer that induces settlement of the abalone larva, and the coralline then provides habitat and food for the tiny abalone; the coralline in turn benefits from the grazing of the abalone on its surface.

***Gnathancanthus goetzeei* (Red Velvet Fish) amongst red algae, Stokes Bay, KI.**
(Photograph: David Muirhead).

Some algal habitats have features that provide refuge for unusual or rare species. For example, deep-water red algal communities provide habitat for some rare fish species (J.L. Baker pers. comm.). These include: the southern pygmy pipehorse, *Idiotropiscus australis*, the red pipefish, *Notiocampus ruber*, rosy weedfish, *Heteroclinus roseus*, Forster's weedfish, *Heteroclinus tristis*, Red Indianfish, *Pataecus fronto*, and red velvet fish, *Gnathanacanthus goetzeei*.

Deeper-water red algal habitats often have high species diversity and are comparatively rare on South Australian coasts. Representative beds of red algae are therefore worth conserving in their own right. Notable examples of such habitats recorded are:

- deeper reefs in the SE of SA, notably those 15–40 m off Cape Northumberland, where >200 species of red algae were recorded at a single site (Shepherd 1979);
- deep reefs off the Coorong at depths of 20–30 m (Haig *et al*. 2006).
- deeper reefs at 10–25 m in Backstairs Passage, on both the Fleurieu Peninsula and Kangaroo Island sides;
- reefs at 10–12 m depth ~10 km ESE of Troubridge I., lower Gulf St Vincent;
- deeper reefs in Thorny Passage, especially off Memory Cove at 20–40 m depth;
- reef habitats at 15–20 m depth in Anxious Bay, off Ward I., Hotspot, Nuyts Reef, and isles of Nuyts Archipelago in the eastern Great Australian Bight.

***Palmoclathrus stipitatus*.**
(Photograph: Kevin L. Brandon)

Some algae have very restricted distributions or are known from very few habitats. An outstanding example of this is the green alga *Palmoclathrus stipitatus*. This rare and remarkable alga has a stem that shows annular rings, out of which grows a delicate, cup-shaped, perforated membranous blade. Individual plants up to 8 years of age have been recorded (S.A. Shepherd unpublished data). The plant is known mainly from deeper water reef habitats in Anxious Bay at 15–20 m deep, and 3-4 km off Cape Northumberland at depths of 40–60 m, where the plant forms extensive mono-specific beds. The species also occurs in shallow water in caves at 10–15 m depth on the northern face of Waldegrave I., eastern GAB.

Threats

The major threats to algal forest habitats dominated by kelp or fucoid algae are excess nutrients and sedimentation. These tend to increase in densely populated coastal areas, where land use has intensified, and storm-water run-off and effluent discharges from industry and sewage treatment plants have increased. Offshore dredging and coastal construction also cause increased sedimentation.

The effects of excess nutrients are the decline and disappearance of algal forests and their replacement by algal turfing species 1–2 cm high (Connell 2008; Connell *et al*. 2008). The combination of nutrients and sedimentation are synergistic, and can dramatically increase low, algal turfs (by 77% in a study by Gorgula and Connell 2004).

Sedimentation alone is a stress on algal forests and can eliminate most species in an assemblage, to be replaced by low algal turfs, which themselves accumulate sediment, and prevent a return to the former forest habitat. Hence the final 'alternative state' becomes stabilised. In some cases in eastern Gulf St Vincent, the algal forest has been replaced by mussels, which are favoured by the increased nutrients, and again become stabilised. Examples of the above switch from algal forest to a degraded alternative state are the numerous reefs in eastern Gulf St Vincent from Port Noarlunga north to Outer Harbour (Turner *et al*. 2007; Connell 2008; Gorman and Connell 2009).

Algal forest replaced by mussel bed, Gulf St Vincent.
(Photograph: Alison Eaton)

Another threat to the integrity of algal communities is climate change, notably acidification of coastal waters. Little is as yet known about the effects, except that some algae e.g. calcified species, such as crustose corallines, will be deleteriously affected (Hall-Spencer *et al*. 2008), and that synergisms will occur, as in the accelerated expansion of turfing algae in the presence of nutrients (Russell *et al*. 2009). Other effects may be the disappearance of calcifying animals, such as grazing sea urchins or molluscs, with consequent cascading effects on algae.

Seawater temperature increases due to climate change are also likely to result in a suite of cold-adapted large brown algae retreating out of SA state waters over the next few years to decades. These include *Durvillaea* and *Phyllospora* mentioned above as well as the giant kelp *Macrocystis pyrifera* (var. *angustifolia*) that is covered by a separate chapter. All of these species are presently confined to the SE of the State, where they benefit from cold, nutrient-rich waters in summer from the Bonney Coast upwelling. If the intensity of upwelling increases then they may stay in State waters but it is also likely that the passage of high-pressure systems will move south of their present path and so miss SA. In that case then their climate-change driven retreat would be hastened.

Considerations for Marine Protected Areas (MPA's) in South Australia

The very high productivity of algal forest systems, the diversity of canopy and understorey species implies that they are also places of high biodiversity, and should be well represented in all sanctuary zones and habitat-protection zones in the marine park system throughout the State. The threats to their integrity are mainly anthropogenic, from which it can be concluded that sanctuary zones containing them are best located adjacent to coastal terrestrial parks, from where nutrients and stormwater run-off are minimal.

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Estuaries

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Definition and description

In South Australia, an estuary has been defined as "a partially enclosed coastal body of water, including its ecosystem processes and associated biodiversity, which is either permanently, periodically, intermittently or occasionally open to the ocean within which there is a measurable variation in salinity due to the mixture of seawater with water derived from on or under the land" (*Natural Resources Management Act 2004).*
Under this definition, Gulf St Vincent and Spencer Gulf are not recognised as estuaries, but the definition does include the smaller estuaries within these gulfs[1].

The Coorong.
(Photograph: Coast Protection Board)

Estuaries are generally classified on the basis of their geomorphology or hydrology. In terms of hydrology and meteorology, Australian estuaries can be classified into five groups: Mediterranean (comprising approx. 10% by number of Australia's estuaries), temperate (12%), transitional (5%), arid tropical or subtropical (6%), and wet and dry tropical or subtropical (68%)(Eyre 1998). Although Eyre (1998) considered Mediterranean estuaries as generally occurring in Western Australia, the Mediterranean climate of winter rain and summer drought also occurs in SA (Klausmeyer & Shaw 2009). Seven main geomorphological types of estuaries are found in Australia with most of these also found in SA: wave-dominated estuaries (e.g. Coorong and Lower Lakes, Lake George), coastal lagoons and strand plains (none in SA), drowned river valleys and embayments (e.g. many of the West Coast bays), tide-dominated estuaries (e.g. Northern Spencer Gulf[2]), tidal creeks and tidal flats (e.g. Gawler River, Port River Barker Inlet System), wave-dominated deltas (e.g. Hindmarsh and Onkaparinga Rivers)

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[1]There are, however, over 40 definitions of an estuary, and under many of these Gulf St Vincent and Spencer Gulf would be considered as two of the world's largest inverse estuaries (an estuary where salinity increases towards the upper reaches) Nunes RA, Lennon GW (1986) Physical property distribution and seasonal trends in Spencer Gulf, South Australia: an inverse estuary. Aust J Mar Freshwat Res 37:39-53.
[2]Northern Spencer Gulf is considered a tide-dominated estuary based on the Australian-wide database, OzEstuaries.

and tide-dominated deltas (e.g. Light and Tod Rivers) (Turner *et al*. 2004, Gillanders *et al*. 2008). Most Australian estuaries, including South Australian ones, are shallow due to tectonic stability and low coastal relief (Eyre 1998). Geomorphology may affect key hydrological processes such as flushing times, but links between terrestrial and marine systems are more likely to be affected by hydrological classification (Eyre 1998).

The dominant vegetated habitats within estuaries are seagrasses, mangroves and saltmarshes (see other chapters). *Melaleuca* (paperbark) swamps may also occur in low-lying areas adjacent to estuaries between terrestrial and tidal vegetation; for example, at Chapman Estuary on Kangaroo Island *Melaleucas* fringe the shoreline. Rocky shores and reefs may also occur in association with estuaries, particularly in drowned river valleys and embayments (e.g. American River). Rocky habitat may also be an artificial habitat component of estuaries where rock walls are now used to keep the estuary mouth open (e.g. Patawalonga Creek) or secure residential/industrial land (e.g. upper Port River). Non-vegetated habitats comprising soft sediments (e.g. sand and mud, intertidal mudflats, sandy shoals and beaches) occupy the greatest area of many estuaries. The final habitat within estuaries is the open water.

***Melaleuca halmaturorum*, Hindmarsh River.**
(Photograph: Ron Sandercock).

Distribution

OzCoasts currently identifies 38 estuaries in South Australia, 16 of which are considered to be wave-dominated, 18 as tide-dominated, and four as river-dominated (see examples above). This contrasts with State Government reports which list 102 estuaries in South Australia (DEH 2007, Rumbelow *et al.* 2010). Estuaries occur from Tourville Bay in the west through to Glenelg River on the Victorian border, although the greatest concentration is along the northern coast of Kangaroo Island, along the Adelaide metropolitan coast and around the Fleurieu Peninsula. A number of those listed in the interim map have been dry for some time, indicating either little freshwater input or water that flows underground (e.g. Breakneck River, Kangaroo Island). Many others dry up seasonally (e.g. Deep Creek, Fleurieu Peninsula) or may be sustained by springs (e.g. Deep Creek, Kangaroo Island). The most iconic and well studied of the South Australian estuaries is the Coorong and Lower Lakes at the mouth of the Murray River (e.g. Lester & Fairweather 2009, Paton *et al*. 2009, McKirdy *et al*. 2010).

Function

Estuaries are critical transition zones linking land, freshwater habitats and the sea (Levin *et al*. 2001). They provide many ecosystem services and functions including erosion control and storm surge protection, filtration of water as it flows from land to sea, regulation and cycling of nutrients and habitat for plants and animals. Costanza *et al*. (1997) provided a summary of the average global value of annual ecosystem services for a range of biomes and showed that estuaries had the greatest value per hectare, and significantly greater value than coral reef habitats.

A variety of organisms move into, out of, or across estuaries during one or more stages of their life history. Estuaries may be used as spawning habitat, nesting sites, nursery grounds, adult habitat, feeding grounds, refugia or as a dispersal corridor. Some species will spend their entire life within the estuary, whereas others may use estuaries for a portion of their life cycle (e.g. for the juvenile stage of their life history). Terrestrial organisms may feed on animals within estuaries, although the majority of examples are from the northern hemisphere (e.g. brown bears). Birds are also an important component of estuaries. Estuaries are thought to provide not only physical structure that provides refuge from predators but also higher food availability than adjacent freshwater or marine environments. Because a large number of juvenile invertebrates and fish occur in estuaries, they may also attract predators to feed in estuaries.

Royal spoonbills, Coorong.
(Photograph: Paul Wainwright).

Threats

Estuaries are among the most degraded ecosystems on earth. Of the 38 estuaries listed in OzCoasts, almost 70% were categorised as modified or extensively modified. Only three estuaries in South Australia (Breakneck River, Kangaroo Island; Smoky Bay and Tourville Bay, Eyre Peninsula) were regarded as near pristine and a further nine estuaries, including eight on Kangaroo Island, were regarded as largely unmodified. The key threats facing estuaries relate to changes in catchment hydrology, natural land cover and use, impacts associated with floodplain habitats, alteration of tidal regimes and estuarine use.

Catchment Hydrology

Catchment hydrology has changed significantly since European settlement. Many estuaries now have altered freshwater flows due to dams, weirs etc restricting freshwater input (Gillanders & Kingsford 2002).These restrictions mean that the timing and extent of freshwater input has changed considerably. In addition, groundwater extraction also occurs (e.g. Baird Bay, Blanch Point), and there can be substantial stormwater input. In some catchments, stormwater and its associated silt, nutrients and heavy metals discharging directly into the estuary has created problems.

Water abstraction and storage in upstream areas can result in reduced freshwater flows to estuaries leading to the closure of estuary entrances and alteration of salinity within the estuary.

Although flow-related data are not available, estuarine regions of the Onkaparinga are becoming more saline, as evidenced by increasing trends for electrical conductivity, total dissolved solids and suspended solids (Nicholson & King 2004). Increases in salinity may lead to changes in species composition and fish kills (see Hoeksema *et al*. 2006 for an example from Western Australia). The marine component of estuaries has also been modified, with subsequent alterations to the tidal regime, via dredging and construction of levees (e.g. Port Pirie), barrages (e.g. Coorong) and causeways (e.g. Franklin Harbour). Some estuaries also have modified entrances and seawalls/groynes added (e.g. Port River Barker Inlet).

Land Clearance

Substantial clearing of the natural cover of catchments has occurred, with many estuaries now surrounded by extensive agricultural, industrial or urban land. For example, over 60% of the catchment of Baird Bay has been cleared for agriculture. Altered catchment land use can impact on sediment and nutrient input to estuaries. Agricultural practices can affect both pollutants and water flow into estuaries. For example, agricultural land use in a catchment can lead to high levels of nutrients (Nicholson & King 2004), thereby affecting overall water quality. Flood plain areas have also been extensively altered such that much of the riparian vegetation, which would traditionally have filtered out pollutants, has been lost. Acid sulphate soils (e.g. Port Pirie, Port Broughton estuary) may also be a problem in some estuaries. Acid pH conditions of waters have been recorded in some estuaries (e.g. Carrickalinga).

Coastal Development

Coastal development is also increasing significantly as more and more people wish to live by the coast. Besides residential development along the edges of estuaries, which may result in vegetation clearance, disruption of sand movement and increased stormwater and sewerage problems, marinas and jetties have been constructed within estuaries (e.g. Wirrina Cove, Patawalonga). Associated with increased development is access to off-road tracks and vehicle use of beaches, both of which can disrupt sand movement and the natural amenity of estuaries.

Human Use

Estuaries are used for a variety of purposes including commercial and recreational fishing, aquaculture, maritime transport and port development. Sources of pollution include thermal discharges from power stations (e.g. Port River Barker Inlet), factory chemicals, fertilisers and pesticides from agricultural and horticultural land, and hydrocarbon leaks and spills from boating and shipping.

Marine Pests

Significant potential exists for South Australian estuaries to be affected by introduced species especially where shipping is common (e.g. Port River Barker Inlet, Port Pirie). Local boat traffic also has the potential to translocate species from the site of their initial introduction. Whilst a range of introduced species are known from South Australian waters, probably the key threat for estuaries is *Caulerpa taxifolia* (aquarium *Caulerpa*) (Cheshire *et al*. 2002). Species richness of fish in *Caulerpa taxifolia* habitats was lower than in native seagrasses (*Zostera* and *Posidonia*) and the assemblage structure differed, suggesting that this invasive

***Caulerpa taxifolia*, Port River Estuary.**
(Photograph: Greg Collings)

green alga has potential to impact fish(York *et al*. 2006).Other introduced species include Pacific oysters (e.g. Blanch Point, Coffin Bay, Franklin Harbour) which, whilst forming a significant aquaculture industry, may colonise natural rocky habitats.

Climate Change

Climate change is also likely to greatly impact estuaries, but effects may be more complex than in open ocean waters. Despite this, there have been few studies that have investigated climate change implications for estuaries (see Gillanders *et al*. submitted for a review)Estuaries are likely to be affected by a number of climatic and hydrologic variables that influence both freshwater and marine systems. Surface ocean pH is predicted to decline significantly by the end of the century and in estuaries there may be other natural and anthropogenic processes (e.g. additional nutrient inputs, acidic river inputs) that compound pH problems (Feely *et al*. 2010). Predictions for southern Australia of drying conditions, and increases in temperature are likely to impact salinity of estuaries especially where there is restricted circulation. Many of SA's estuaries already show inverse salinity gradients year round or during summer months (Gillanders unpublished data).Strong correlations between salinity and fish assemblages have also been found (Gillanders unpublished data). These data suggest that with climate change some species may be lost. Others may be outside their optimum environmental conditions and whether they can adapt will depend on their life cycle and coastal currents. Changes to estuarine mouth morphology and closure are likely in wave-dominated estuaries and deltas thereby impacting fish species that move into or through estuaries.

Vulnerability of South Australian estuaries

Estuaries are particularly productive systems (Costanza *et al*. 1997, Beck *et al*. 2001), but are also at risk from a wide range of anthropogenic impacts acting on freshwater, terrestrial and marine systems. The importance of estuaries in South Australia has been recognised through protection via aquatic reserves. Despite this, many estuaries considered near pristine, as well as the full range of geomorphological types of estuaries and a range of estuaries with various types of salinity gradient remain unprotected. Given the South Australian Mediterranean climate (wet winters, dry summers) our estuaries differ greatly from those in other states, with the possible exception of the southern West Australian estuaries.

Estuaries generally show high natural variability in a range of environmental parameters, which can change on tidal and seasonal scales, as well as in response to rainfall. The species utilising estuaries have generally adapted to this variable environment. Thus, estuaries are generally regarded as resilient since they can often withstand a range of natural and anthropogenic stressors. However, SA estuaries are considerably smaller than their European and North American counterparts where general views of estuarine resilience were developed. The variable rainfall, considerable extraction of freshwater and high evaporation rates makes SA estuaries particularly vulnerable to additional impacts.

Recommendations for MPA's in South Australia

Several estuaries are currently protected in aquatic reserves (American River aquatic reserve, Port Noarlunga aquatic reserve which encompasses the Onkaparinga estuary, Barker Inlet – St Kilda aquatic reserve and St Kilda – Chapman Creek aquatic reserve). These aquatic reserves were primarily setup for conservation of mangrove, seagrass or mudflat assemblages, as well as protection of juvenile habitat for major commercial and recreational species. In the case of St Kilda – Chapman Creek aquatic reserve it also provides a buffer area between commercial fishing and Barker Inlet aquatic reserve. Although aquatic reserves exist and prevent some types of activity (e.g. bait digging, fishing and collection of marine organisms), adjacent land use may also influence the degree of protection of aquatic waters. Thus, reserves with adjacent terrestrial conservation areas may provide better protection of estuarine waters than reserves adjacent to industrial or agricultural lands.

It is recommended that marine parks encompass estuarine environments and that a range of types of estuaries (based on geomorphology and salinity gradients) are included. It is particularly important that estuaries that are still in good condition are included in marine parks. Consideration should also be given to including the adjacent coastal waters. Education of the general community as to the importance of estuaries and their need for protection will also be important.

Onkaparinga estuary
(Photograph: DEH)

Conclusion

Estuaries are highly productive and of considerable value, yet are some of the most degraded systems on Earth. South Australian estuaries are widely distributed across the state and cover a diversity of geomorphological types. Few estuaries are regarded as near pristine and the vast majority are vulnerable to a range of threats influencing terrestrial, freshwater and marine systems. Probably the greatest threat facing many SA estuaries given our Mediterranean climate is climate change. Few estuaries are protected in aquatic reserves, and given the importance of estuaries and their vulnerability; there is a need to consider protecting many more via the marine parks process.

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Intertidal Seashores

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Description and distribution

The strip of land that fringes our seas and lies between the extremes of tides constitutes an important series of coastal environments that are accessible to many people and therefore well-studied. Covered by high tides but exposed during low tides, these intertidal zones are often the main part of the sea that the widest range of the public interacts with for recreational or other pursuits. Indeed many people's interaction with the sea starts with them dabbling in rock pools as a child. Intertidal seashores can be vegetated (in which case those habitats are named for the seagrass, mangrove or saltmarsh plants that dominate them visually, see other chapters in this vulnerability series for those), or be mainly bare and hence are named for the physical features of the substratum. The latter include rock platforms, sandy beaches, boulder fields, rock pools, sea cliffs, tidal flats, mudflats and cobble shores. They often intergrade at their higher ends into saltmarshes or cliffs and at their lower ends into seagrass meadows, subtidal mud or sand flats or subtidal reefs.

Intertidal beach, lower southeast.
(Photograph: Sarah Bignell).

This paper reviews the features and vulnerability of some intertidal habitats, namely rocky seashores, sandy beaches and mudflats that are found within South Australian waters (see also Fairweather 1990; Fairweather & Quinn 1995; Fairweather 2003; Dittmann 2007; Benkendorff *et al*. 2008 for reviews relevant to South Australia). South Australia has long shoreline extents of all three types of intertidal habitat: rocky, sandy and muddy shorelines. Rocky shores and sandy beaches tend to dominate the open coast but muddy sandflats tend to replace them up both the Gulfs and in enclosed bays (due to less water movement).

Function

Intertidal habitats are quite narrow in extent but relatively open systems that rely upon other marine habitats (esp. the nearby pelagic habitat) for connectivity. The regular, alternating exposure to air at low tide and coverage by seawater at high tide means that the conditions that intertidal organisms face vary widely but regularly. Organisms attached to or moving over hard substratum that lies within the surf zone for at least part of the time can suffer extreme conditions from wave action. For these reasons rocky intertidal organisms have long been of interest to physiologists, ecologists and evolutionary biologists studying how harsh conditions can shape organisms, populations and communities.

Anemone in rock pool, French Point, lower southeast.
(Photograph: Sarah Bignell)

There are at least four relevant gradients (Raffaelli & Hawkins 1996) that define the environmental conditions that intertidal organisms face: relative height on the shore; exposure to waves and other water movement; salinity of the water; and the particle size of the benthic substratum. Understanding where an organism or habitat fits on these four gradients provides a swift insight into the challenge each faces from the marine environment (Fairweather 2003). At a larger scale, it is clear that each of these gradients varies enormously across the seashores of South Australia, from some of the most exposed shores (e.g. southern Kangaroo Island or near Elliston) to the calm of the upper Gulfs, from a few estuaries through oceanic seawater to the hypersaline waters of the upper Gulfs and the Coorong, and from fine muds in parts of the Gulfs through to the spectacular cliffs of the Great Australian Bight. In South Australia we tend to have a narrow tidal range (e.g. mostly less than 2m or "microtidal"), except up the Gulfs where the tidal range tends to be larger (thus there you find wide tidal flats).

Rocky seashores overseas are amongst the best-studied marine habitats, providing many examples of field experimentation to test scientific hypotheses and theoretical work that has shaped the broader scientific discipline of ecology (e.g. see Underwood & Chapman 1995; Raffaelli & Hawkins 1996; Underwood *et al*. 2000; Bertness *et al*. 2001; Connell & Gillanders 2007; Denny & Gaines 2007; Polunin 2008; Little *et al*. 2009). Within Australia, much is known about the ecological patterns and processes on rock platforms especially near Sydney (e.g. see Underwood & Chapman 1995, 2007) and a few other metropolitan centres but comparatively very little work has been done in South Australia. Some of that is older and descriptive in nature for either all SA coasts or specific locations near Adelaide or on Kangaroo Island (e.g. Womersley & Edmonds 1958, 1979; Womersley & Thomas 1976; Thomas & Edmonds 1979; Benkendorff *et al*. 2008).Other, more remote locations have received some attention more recently (e.g. Benkendorff 2005).Relatively little experimental work has been done in South Australia compared with elsewhere (but see Chilton & Bull 1984, 1986 for a not-so-recent example). The rock types do vary enormously along the State's coastline, from soft to friable calcarenite (aeolinite) in the South East (the so-called 'Limestone Coast') to hard granites and gneiss of some offshore islands and mainland outcrops. This affects the slope of the shore, hardness of the substratum and the sorts of microhabitats (e.g. rockpools, crevices, boulder fields) found on the shore and hence their biodiversity (Benkendorff *et al*. 2008).

In contrast, sandy beaches were the least-studied marine habitat in Australia during the 1980s (Fairweather 1990) and the situation has barely improved since (Dugan *et al*. 2010). Indeed many soft-sediment ecosystems (from exposed sandy beaches to calm mudflats) have been studied more by geographers or geomorphologists than dedicated ecologists or biologists (Fairweather & Quinn 1995; Short 2006), and this may be even more so in South Australia (Benkendorff *et al*. 2008). Unlike working on rock, the difficulty of keeping experimental installations in place in sand makes doing long-term field experiments much more difficult and so the tradition of research work is rather different on soft sediments (Fairweather & Quinn 1995). The theoretical underpinning of ecological principles (McLachlan & Brown 2006; Gray & Elliot 2009) and their contribution to overall ecological theory has been some what less than for rocky shores but this may reflect the fewer ecologists that study them. Sandy beaches range across morphological types from reflective through intermediate to dissipative (see Short 2006 generally and Benkendorff *et al*. 2008 for discussion of this in relation to Gulf St Vincent), along with increasing abundances, biomasses and richnesses of animals living on and in the sands. The Coorong beach is one of the longest on the planet and a truly dissipative beach that is very rich in biota and so has been sampled by scientists visiting from overseas (McLachlan *et al*. 1996).

Tea Tree Crossing, Coorong.
(Photograph: DEH)

Threats

Intertidal areas can be impacted by human actions from both the land and the sea sides (Thompson *et al*. 2002; Branch *et al*. 2008). Unlike many other marine habitats there is little commercial exploitation of intertidal organisms because most fishing gear does not work in intertidal zones. The one component of the biota in any of these habitats that is regularly sought commercially tends to be burrowing bivalves in sandy or muddy habitats (e.g. the pipi or Goolwa cockle *Donax deltoides* along the Coorong beach, see the Shellfish Beds Habitat Vulnerability chapter in this series for more on this). Instead the recreational impacts upon intertidal zones are more of a concern than any commercial exploitation (Brown & McLachlan 2002; Brown *et al*. 2008).

Thus many of the key threats to seashores arise from their accessibility and thus people visiting them and what they do there. The simple act of walking results in trampling, this can have quite an impact by crushing or displacing organisms (Povey & Keough 1991; Moffett *et al*. 1998) on both hard and soft shores but also by compacting or disturbing soft sediments. Likewise, using vehicles on sandy or muddy flats can result in wheel ruts or flattened areas that require some time to be changed back by waves (for sandy beaches, Lucrezi & Schlacher 2010; Ramsdale 2010) or the more gradual bioturbation (in muddy shores). Like in saltmarshes, these anthropogenic features may persist for a long time as lines of compacted sediment and preferential drainage. Also associated with recreational activities are effects from overturning boulders and just “poking around rockpools”, litter, cleaning of beaches, ecotourism behaviourally affecting birds or other biota on the beach, or recreational angling with rod and line or seine netting from the beach. Recreational impacts are likely to increase greatly in the future due to more leisure time and an increased ability to reach far-flung places (Thompson *et al*. 2002).

Harvesting of organisms from the seashore for food is a tradition extending back to indigenous culture but also a feature of many white settler communities since. It is currently illegal to collect any organisms from any rocky reef down to 2 metres depth anywhere in the State but this laudable law is hardly ever enforced. Thus it is often possible to find family groups scouring some seashores for shellfish and algae to eat, and rock platforms close to Adelaide and other population centres tend to be depleted (Benkendorff *et al*. 2008).Digging or pumping for bait is common in many muddy or sandy sediments (and associated habitat features like deposited piles of wrack) and this activity can disturb the three-dimensional structure of the sediments as well as lead to removal of the target organisms.

Bait digging
(Photograph: Ron Sandercock)

Any earth works or other development that affects the drainage patterns in muddy or sandy habitats can have large effects upon the suitability of those locations for the organisms that would normally live there. Likewise offshore or land-based structures such as groynes or jetties can affect waves and currents in the adjacent intertidal areas. Any disruption of the sand budget by development in the dunes or offshore and subsequent “hardening” of the coastline will affect sandy shores, often leading to erosion deficits (and hence the need for sand replenishment as occurs along Adelaide’s coastline). Mining for minerals in beach sands is not widespread in South Australia but may increase as the global demand for such minerals continues to grow.

Intertidal areas also tend to be vulnerable to pollution coming from the land (e.g. stormwater as well as the disposal of wastes. Pollutants tend to accumulate in embayments because of reduced circulation, for example chronic nutrient pollution may lead to impacts from eutrophication and harmful algal blooms. Relatively few exotic species (mainly the European green crab *Carcinus maenas*) are found on SA seashores but the aggressive removal of the reed *Spartina* sp. by PIRSA Biosecurity may do more harm due to compaction and other impacts made by bulldozers (e.g. at Middle Beach in 2005).

Climate change is thought to be an important factor in the future of intertidal organisms and habitats. Sea-level rise will impact upon many of these habitats because the natural response of retreating inland is not available in many places due to human habitation and uses (this loss of habitat area is often termed “coastal squeeze”, Doody 2004). Increased storminess and other extreme weather events will also hit many intertidal habitats hard, with the loss of beaches and tidal flats likely. Changes to circulation patterns would affect the delivery of larvae to these shorelines and increased temperatures are likely to lead to range shifts of organisms toward the poles.

The exact effects of such disturbance depends on the extent of natural sources of disturbance, to which organisms may be adapted but will also interact with any human-induced effects. That adaptability relies on the natural regime of disturbance that an organisms will have evolved over time to cope with but then any anthropogenic disturbance may occur in addition to what naturally happens. In that case, the human-induced plus natural disturbances may exceed the organisms capacity to cope. Muddy shores tend to be more susceptible than sandy or rocky shores to impacts from vehicles, trampling, digging and dumping because of less water movement over them. Rocky seashores tend to be the least susceptible (due to their hard substratum and relative lack of fragile biogenic structures; Thompson *et al*. 2002; Branch *et al*. 2008) and also more resilient (due to their open nature) as long as unimpacted habitats are near enough to act as sources of recolonists (usually as larvae or spores). Indeed their resilience in the face of impacts like oil spills is quite remarkable (e.g. a 3-5 year recovery time, Thompson *et al*. 2002), as long as effects are not compounded by the use of more toxic dispersants.

Vulnerability

The vertical cliffs in the far west and elsewhere of the State are largely inaccessible and their narrow intertidal zones are not so vulnerable. Horizontal rock platforms and their boulderfields, rockpools and other microhabitats are more vulnerable to human impacts, especially where they consist of softer rocks and erode quickly and can be damaged by human actions. Sandy beaches tend to be resilient (and naturally changeable) but it is hard to judge how rich they are when most biodiversity is buried during the day or transient in nature (e.g. active at night or high tide). Thus levels of ecological damage to our beaches may go unnoticed without dedicated sampling. In contrast, many of the wide tidal flats of the Gulfs have already been used for habitation or transport and the proportion left is under further threat (esp. if sea levels rise dramatically over the next 50 years). Any of the rocky, sandy or muddy locations closest to our cities or towns are at risk from being “loved to death” from recreational usage, at least during the summer holiday season and over the coming years as our human population grows and reaches further.

Intertidal reef, Wright Bay
(Photograph: Peter Fairweather)

Considerations for MPAs in South Australia

The already-protected component of intertidal seashores within South Australia needs to be expanded because there are some obvious gaps. For example, most Aquatic Reserves in this state feature soft rock types (e.g. limestones or aeolinites) rather than harder volcanic rocks, which influences the assemblages found there (Benkendorff *et al*. 2008). The present protection from collecting on rocky reef (to 2 m depths) is rarely ever enforced anywhere in the State. Very few beaches enjoy any level of protection and even muddy shores suffer routinely from illegal vehicle usage or dumping of wastes such as household rubbish or building refuse.

Because of the ubiquity of intertidal zones with some vulnerability (see above) along the whole coastline of South Australia, as a general rule the higher levels of protection (e.g. Sanctuary or Restricted Access Zones) should extend to and include the coastline in numerous places.

Conclusion

Intertidal seashores are important as the first point of contact, usually during childhood, that most people have with the sea, oceanic habitats and marine organisms. Despite this familiarity, they can be "loved to death" and suffer wherever they are excessively used by South Australians. Thus they deserve protection from over-use by growing populations with more time to recreate and the ability to go to wilder places. The contiguity of intertidal shores with the subtidal habitats below them (especially reefs) and the supratidal ones further inland (e.g. saltmarshes, dunes, seacliffs) is also important to maintain if we are to conserve South Australia's marine biodiversity in its fullest manifestation.

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Macrocystis (giant kelp) forests

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Description

The giant kelp is the largest marine plant on earth with a maximum recorded length of ~30 m in SE Australian waters (Cribb 1954). It forms a forest with a floating canopy off the SE coast of S.A., and as vividly described by McPeake *et al*. (1987) "*the spreading fronds form a golden-hued canopy that stands out against the vivid blue of the sea.*" From the holdfast a cluster of stipes emerge that branch and grow toward the surface as fronds, each bearing a series of bladders that keep the plant afloat. At the base of the plant other short stipes grow and produce small, branched blades, called sporophylls, which hold the gamete-bearing sori.

Until recently two species had been acknowledged as present in SE Australia – *Macrocystis angustifolia* and *Macrocystis pyrifera.* However recent evidence, based on the genetic relatedness of different forms and their inter-fertility, suggests there is one variable species, *M. pyrifera* (Coyer *et al*. 2001, Macaya and Zuccarello, 2010).

Detail of *Macrocystis pyrifera* showing stipes and floatation bladders, lower southeast.
(Photograph: Gordon Bignell)

Distribution

On mainland Australia, forests of the giant kelp are found from Cape Jaffa to Walkerville, Victoria. Along much of the SE coast of S.A., fringing reefs occur, partially protecting inshore lagoons and bays from extreme swell conditions. Inside the fringing reefs kelp plants are abundant at depths of 2–10 m, not as dense forests, but as scattered individuals at densities of up to 10 per 100 m^2(Figure 2).Outside the fringing reefs, forests can occur at depths of 10-25 (occasionally 35) m, but the forests are patchy in space and time. They appear rapidly after strong upwellings (especially during El Niño years), and persist until winter storms tear them off the bottom. In exposed areas, forests may be present only one out of every 4–5 years, or may come and go on longer time scales. For example, divers have reported that they were scarce during the decade from the mid-1990s, (see Edyvane and Baker 1999), but abundant since 2006.

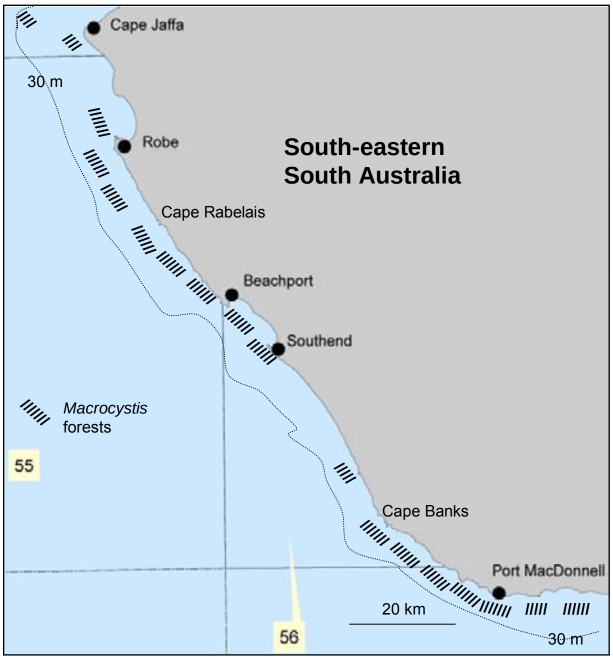


Figure 2. Map of southeast of S.A. showing approximate locations of *Macrocystis* forests

Biology

Macrocystis has a two-phase life cycle, with alternating generations of the giant sporophyte and the microscopic gametophyte. The sporophyte becomes reproductively mature at 9–12 months, and releases male and female zoospores into the water from the sporophylls (Sanderson 1992). The zoospores are the main dispersal stage, and after a short dispersal period of hours to days, the zoospores settle on the bottom, and germinate into microscopic male and female gametophytes, a process that can take up to 40 days. The female gametophyte triggers the release of sperm from a neighbouring male gametophyte, and guides it to the egg. After fertilisation the embryonic sporophyte develops into a giant kelp. In the SE of S.A., sporophytes appear during the upwelling season, although Shepherd (1979) recorded them in winter on blocks placed at 15 m off Cape Northumberland. The life cycle is illustrated in Figure 3.

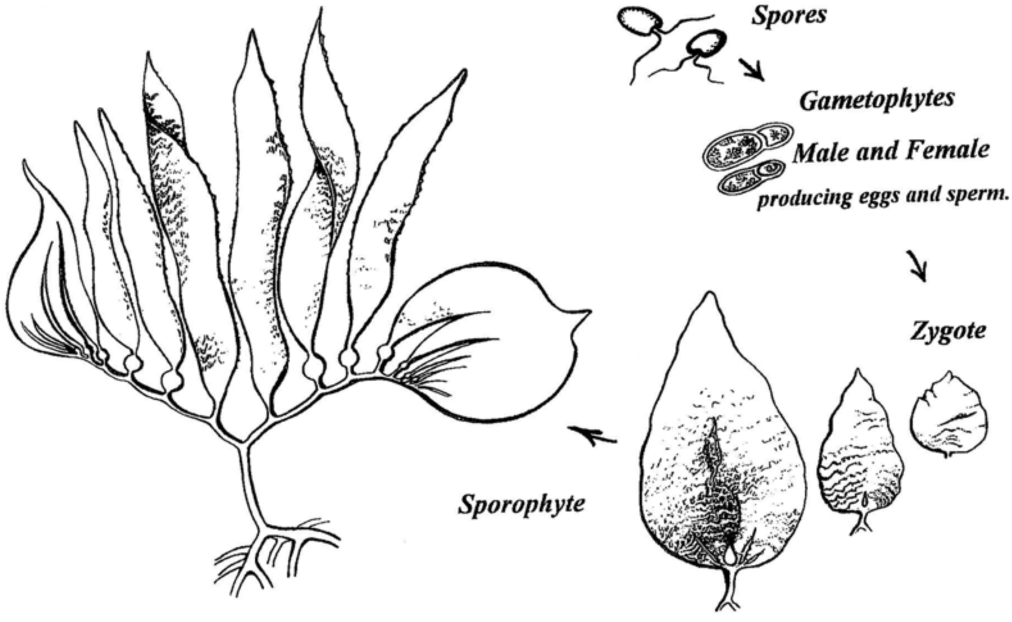
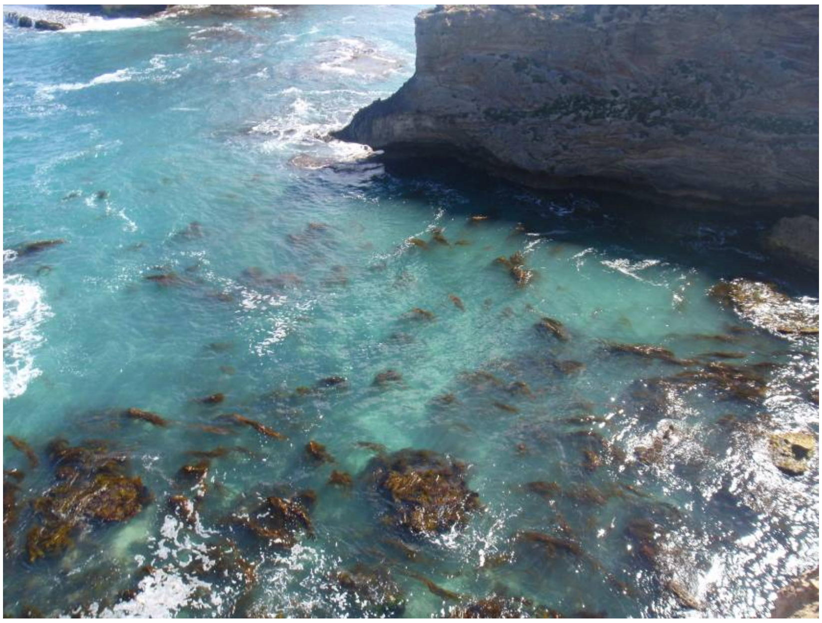


Figure 3. Two-phase life cycle of *Macrocystis* showing the kelp (left), which produces spores that grow into gametophytes, which in turn produce zygotes, that grow into the kelp plant.

The recruitment of sporophytes is greatest during times of high nutrients (>1 μM) and low temperatures (11–19 C). Knowledge of dispersal is critical for understanding the dynamics of giant kelp forests. Field studies have shown that the spores settle within a few metres of a forest, but that where long-shore currents and swell are strong they can be transported up to 10 km (Reed *et al*. 2006). Hence connectivity between kelp stands is strongly influenced by local oceanographic conditions. Where giant kelp forests range along a coastline over a narrow depth-range with long-shore currents, as in the SE of S.A. stepping-stone exchange of spores among neighbouring kelp patches is likely, assisted by drifting fragments of fertile adult plants. To explain the sudden appearance of plants after many months of absence over large areas, some have argued that gametophytes, with their broad temperature tolerances, and the ability to survive in the dark, are the most likely form to comprise a seed-bank (Tom Dieck 1993).



***Macrocystis* viewed from coastal cliffs, lower southeast.**
(Photograph: Sarah Bignell)

Function

Giant kelp beds are among the most productive ecosystems on earth. From studies on growth Sanderson (1992) estimated an annual productivity of 24 kg FW m^{-2}, of which ~20% was lost in erosion of fronds. Like trees in a forest, the giant kelp modifies the environment such that it favours a rich diversity of species – hence the term often applied to it, a foundation species. The physical effects are that it:

- dampens water movement, providing a unique sheltered habitat under the canopy;
- shades the seabed but still permits a diverse under-flora under the canopy;
- stabilises the substratum; and
- due to its architecture provides habitat in the upper canopy, mid-canopy, and within the holdfast for myriads of mobile pelagic, and bottom-living animals.

The biological effects are that it:

- extracts nutrients from the water for recycling;
- provides a rich source of food as drifting kelp blades and dissolved organic matter for animals in and downstream from the forest, and
- functions as a refuge and nursery ground for juveniles to adults of many fish and other species.

The ecological services of giant kelp forests are extensive, as shown by Californian studies, but have not been studied in southern Australia, except for species' lists given by Sanderson *et al*. (2004). However, it is known that blacklip abalone and many other molluscs feed extensively on giant kelp, and lobsters at the next level in the food web feed on many of these molluscs. Hence there is a direct link between giant kelps and two important industries in the SE of S.A.

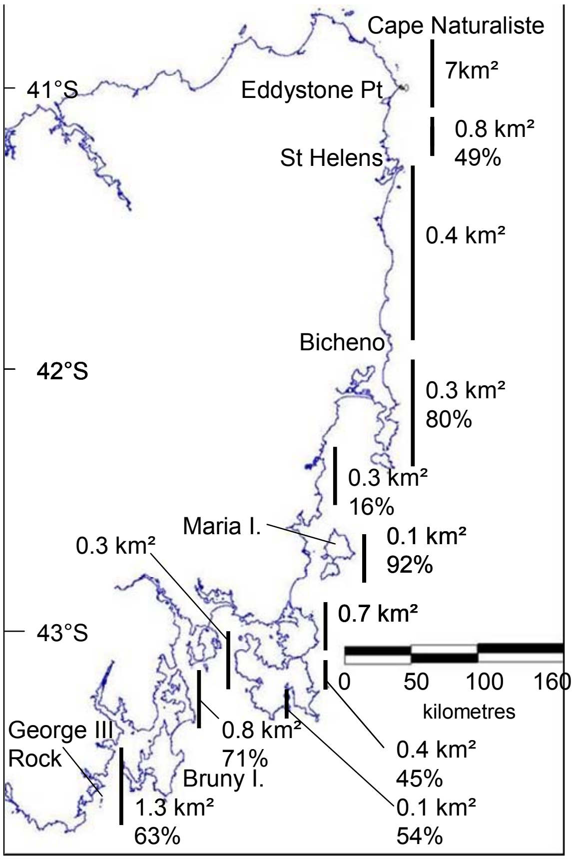


Figure 4. Map of SE Tasmania showing current (2002) areas of *Macrocystis pyrifera* forests, as determined by aerial photography, and the percentage decline since the 1940s (adapted from Edyvane 2002).

Threats

The greatest threat to giant kelp forests in Australia is climate change. In SE Tasmania the east Australia Current has extended further down the east Tasmanian coast, due to a shift to the south of the subtropical convergence. Sea temperatures have increased by 1–2ºC over the past 60 years, and the giant kelp forests have shrunk or disappeared. The extent of this decline at 2003 averaged ~64%, (as shown in Edyvane 2003). Edyvane concluded that the decline was due to oceanographic shifts, coupled with increased episodic storms and dampened reproductive success. Sanderson *et al*. (2004) suggested other factors likely contributed to the decline, including increased sediment load as a result of land-clearing and wood-chipping, increased urchin grazing (a cascade effect from lobster overfishing), and increased competition from the exotic *Undaria*. Re-afforestation trials by Sanderson *et al*. (2004) have had limited success.

Vulnerability

There is a high level of uncertainty about the effects of climate change on the oceanography off S.A. (see Poloczanka *et al*. 2007; Wernberg *et al*. 2009). It is likely that El Niño events will increase in frequency and intensity, upwellings on the SE coast of S.A. will increase, and that the strength of the winter eastward-flowing Leeuwin Current will weaken. Sea temperatures may increase by up to 1°C. The effect of these on *Macrocystis* may be that it will disappear from the Australian mainland as its range contracts to northern Tasmania.

Other changes e.g. acidification and local stressors, such as increased nutrients from anthropogenic/terrestrial sources, will have effects on subtidal reef habitats, especially in semi-protected lagoons and bays (Russell *et al*. 2009), but again, the effects of these on *Macrocystis* are uncertain, but it is possible that the synergistic effects of the totality of changes may see the decline of giant kelp in S.A. as suggested above.

The main fisheries in the SE region are abalone and lobster. Abalone feed on *Macrocystis* as well as a range of other algae, and lobsters predate largely on small to large herbivorous molluscs and sea urchins (mainly the purple urchin *Heliocidaris,* but also *Holopneustes* spp.). The question arises whether a cascade effect is likely, in which lobster overfishing would see an increase in sea urchins, and a consequent overgrazing of algae and the formation of sea-urchin barrens as is happening in SE Tasmania (see Wernberg *et al*. 2009 and references). At present this scenario seems implausible as sea urchins are relatively uncommon; the eastern limit of *Centrostephanus tenuispinus*, which forms small barrens in the eastern Great Australian Bight, is currently Spencer Gulf, but it could conceivably expand its range eastward with warmer temperatures and invade the SE of S.A.

Macrocystis pyrifera **in South East of S.A.**
(Photograph: Helen Crawford)

Considerations for MPA's in South Australia
Given the high productivity of *Macrocystis* and its significant role in shallow benthic reefs, priority should be given to the inclusion of substantial representative areas of *Macrocystis* forests in inshore lagoons and bays along the SE coast in MPAs, both in Habitat Protection and Sanctuary Zones. Sanctuary Zones for *Macrocystis* forests are especially important because they would preserve a representative of an ecosystem, available for future studies of the ecosystem as a whole. As all State governments have agreed since 1994 to introduce ecosystem management of fisheries it is critically important, in order to detect any ecosystem impact of a fishery, to have representative coastal ecosystems which are unfished.

Acknowledgements
The distributional information on *Macrocystis* is a synthesis of observations by the writer, published information, and valuable advice from fishers, which is gratefully acknowledged. Martine Kinloch kindly reviewed the document.

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Mangroves

Hugh Kirkman

Description and distribution

Mangroves are salt-tolerant flowering trees or shrubs forming dense thickets in the intertidal zone. Mangrove forests are usually categorised under the heading of coastal wetlands in most maps or descriptions of coastal environments. The number of mangrove species increases northwards along the Australian coastline up to a maximum of about 30 in northern Queensland. In South Australia (SA) mangrove forests are composed of only one species—the grey mangrove, *Avicennia marina*. *A. marina* grows to about 3.5 to five metres high and has aerial roots (pneumatophores) which project vertically from the sediment surface.

Mangroves in South Australia grow from Tourville Bay in the west to Barker inlet in Gulf St Vincent. They next appear at Barwon Heads in Victoria approximately 660 km east. Mangrove forests covering about 156 km^2 occur in the northern part of the two gulfs and in the bays near Ceduna in South Australia (Fotheringham pers. comm.).

Typically, mangrove habitats are periodically inundated by tides and they grow in waterlogged soil with salinity fluctuating between hypersaline and almost fresh. The aerial roots are an adaptation to obtain oxygen for root growth and metabolism.

***Avicennia marina*, Blanche Harbor.**
(Photograph: Ron Sandercock)

Function

Mangroves in estuaries and coastal waters provide ecological services to the human population living on their shores, and protect the coast from wind damage, salt spray and coastal erosion. They also shelter coastal seagrass beds and reefs from excess sedimentation, enhance fisheries production and create self-scoured navigable channels.

Mangroves can be restored depending on the severity of the natural hazards, the return to suitable conditions, and the climate, the local land use, and the available options to survive extreme events.

Threats

The human impacts on mangroves are well discussed in Bird and Barson (1982) and Hegerl (1982). Here we list them with some discussion but the Bird and Barson and Hegerl chapters add much to this discussion. As coastal development and use by the expanding population continues these areas are more likely to be impacted. Shipping and the likelihood of accidents and oil or other pollution spills will increase.

Mangrove fruit
(Photograph: Simon Bryars)

Development

Early settlers and developers generally considered mangroves as wastelands—places to be filled in and put to “better” use. Thousands of hectares were buried under rubbish or converted to pasture, roads, industrial sites, playing fields and other developments. The most widespread destruction of mangroves and saltmarshes has resulted from landfilling to create sites for industrial areas, harbour facilities, waterfront housing, dumps and sports fields. This landfill can modify patterns of tidal inundation. Once the landfill area is in use, other environmental problems usually follow. Stormwater runoff, acid sulphate soils, accidental spills of pollutants and discharge of treated or untreated effluent cause environmental problems in remaining mangrove forests.

Pollution

Elevated nutrient levels from sewage and stormwater discharges can also affect mangrove ecosystems adjacent to outfalls. The progressive build-up of *Ulva* in the coastal waters of metropolitan Adelaide due to increased nutrients has resulted in the large-scale loss of mangroves (Edyvane 1991; Connolly 1986). In shallow sheltered areas, large drifts of *Ulva* (together with dead seagrass), prevent or retard the establishment and growth of young mangrove seedlings, and also choke established trees by smothering and eventually killing the aerial roots or pneumatophores (Edyvane 1991; Connolly 1986). A major area of 'nutrient-induced' mangrove dieback is the shallow tidal flats between St Kilda and Port Gawler, in particular adjacent to the Bolivar sewerage outfall (Edyvane 1991; Connolly 1986).

Pollution events such as oil spills will immediately kill seedlings and pneumatophores covered in oil will cause mangrove trees to die (Edyvane, 1991).

Acid sulfate soils

Acid sulfate soil is the common name given to naturally occurring soil and sediment containing iron sulphides, principally the mineral iron pyrite, or containing acidic products of the oxidation of sulphides. Mangrove soils contain iron sulphides and when these are exposed to air, oxidation takes place and sulphuric acid is ultimately produced when the soil’s capacity to neutralise the acidity is exceeded. As long as the sulphide soils remain under the water table, oxidation cannot occur and the soils are quite harmless and can remain so indefinitely. Disturbance of potential acid sulphate soils has caused serious economic costs throughout Australia (National Working Party on Acid Sulfate Soils). A proposal to develop a marina and community centre at Ceduna has produced a submission from Wood (2006) that discusses the likelihood of acid sulphate soil production and the problems associated with land change.

Ecological degradation

Straightening meandering tidal channels causes a resultant change in tidal levels and reduced nutrient uptake for the remaining mangroves. Mangrove ecosystems remove nutrients from runoff and river deltas by having meandering streams that slowly release water to the sea. If these meanders are straightened out, for example for boating channels, the water passes quickly to the sea with little chance for nutrients and organic matter to be retained and used in the mangroves. Bund walls and estuarine dredging for flood mitigation cause environmental impacts including destruction of habitat in the dredged area and alteration of channels causing erosion. Hydrodynamic changes to the mangrove habitat have multi-faceted impacts. *Avicennia marina* can survive in conditions that may be two or three times the salinity of seawater. However, it shows signs of stress and much reduced growth rate at these high salinities. Any changes in the freshwater drainage patterns through a mangrove swamp are likely to have a serious effect on its health. Damage to mangroves can occur when the oxygen levels decline in the immediate environment of roots when land immediately behind a mangrove stand is drained or roadways cut through mangrove swamps without the provision of drainage pathways.

Climate change

Carbon dioxide assimilation interacts in complex ways with aspects of mangrove physiology. At higher levels of atmospheric carbon dioxide stomatal conductance is reduced and water loss falls while CO_2 uptake levels are maintained. The result is an increase in water-use efficiency. The trade off between water use and CO_2 acquisition means the mangrove response to high atmospheric CO_2 may combine increased water use efficiency with varying effects on transpiration rate and growth depending on other circumstances. Given the range of temperatures that mangroves experience in their daily lives it seems unlikely that the rises predicted will make much difference to mangrove productivity. Geographic range may be affected depending on topography. This also applies to the effects of sea level rise (Hogarth, 2007).

Vulnerability

The vulnerability of mangrove habitats is multiplied because they fringe the sea preventing easy access for trailer boats and fishermen and because the general public know little of them. Unlike seagrass they are easily seen but were often thought of as a nuisance and a suitable place for local rubbish dumps. As the coast was developed, mangroves were often thought to be in the way and were removed from some places such as Barker Inlet and Whyalla, to be replaced by port facilities or residential or industrial use.

Mangrove forest, Winninowie.
(Photograph: Peter Canty)

The following places are areas where mangroves could be impacted by human disturbance (See Figure 5 for exact locations). On the West Coast: Tourville Bay, Streaky Bay, Smoky Bay, also Denial Bay, Cape Missiessy, Moores Shute to The Bushes in Streaky Bay, Laura Bay and Venus Bay. In Spencer Gulf Tumby Bay, Arno Bay, Franklin Harbour, north of Shoalwater Point and north of Munminni Beach to Whyalla then some in False Bay at Whyalla, on the western side of Fitzgerald Bay, Two Hummock Point to Mangrove Point, Blanche Harbour to Port Augusta. South along the east coast of Spencer Gulf: Port Flinders, Port Pirie, Port Broughton, Warburton Point, Price, Clinton 45 km^2. From the head of Gulf St Vincent to Bald Hill Beach, then starting north of Middle Beach to Port Gawler and Barker Inlet.

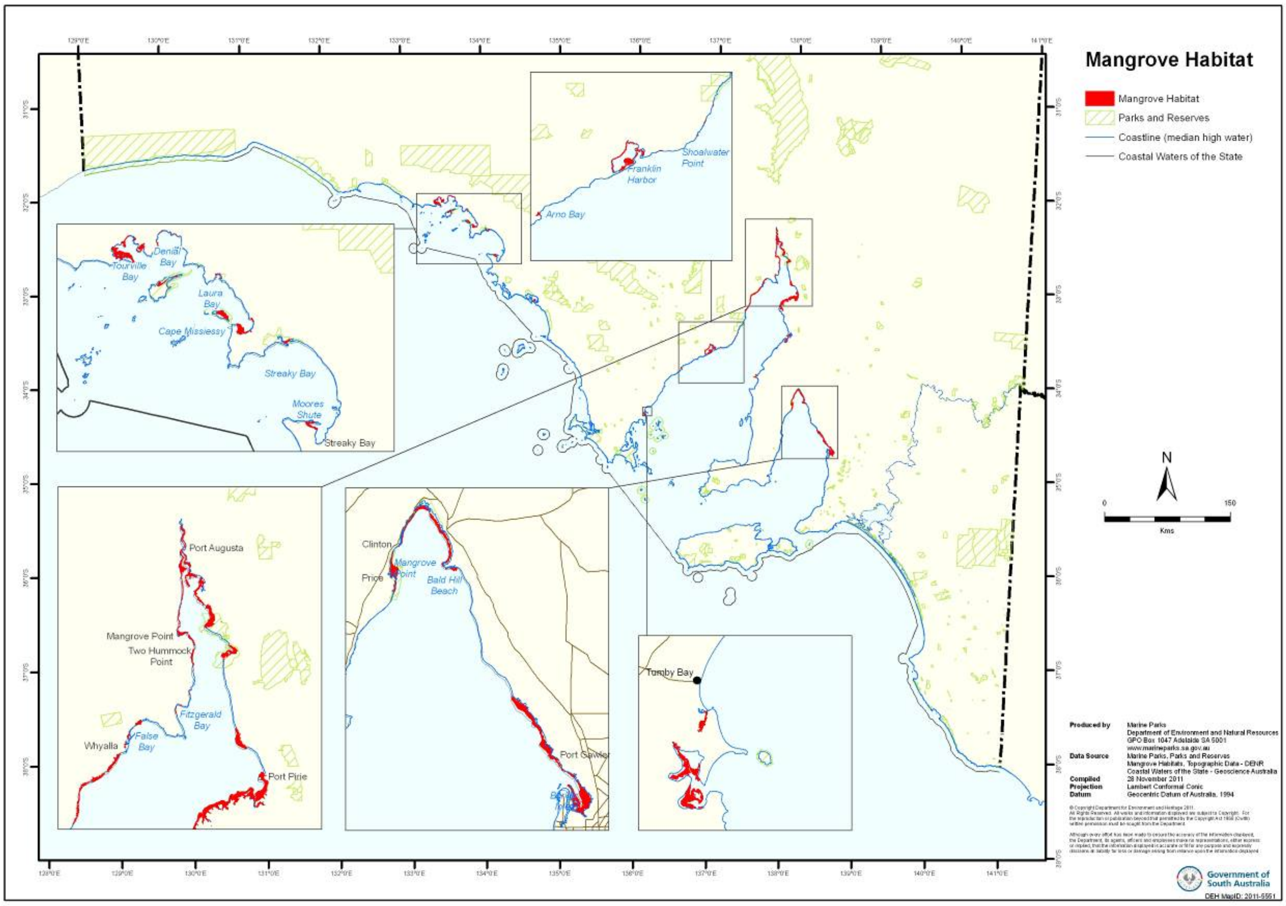

Figure 5. Map showing areas of mangroves around South Australia.

This list is incomplete as are the areas cited (from Edyvane, 1999). Maps of mangroves can be seen in DENR's NatureMaps website (www.naturemaps.sa.gov.au) or Google Earth®. These websites were used to determine the likely effects and disturbance to which the mangroves would be subjected.

The monitoring of the 'Era' oil spill in upper Spencer Gulf revealed that approximately 23 hectares of mangroves were killed or totally defoliated in heavy oiled areas (Butler 1993, Wardrop *et al*. 1993) and showed no sign of significant recovery two years post-spill (Edyvane, SARDI, unpubl. data). No hydrocarbons were detected in benthic sediment samples collected within the upper Spencer Gulf region or in flesh from collected fish and crab.

The full extent of nutrient-induced mangrove loss in the metropolitan Adelaide region has not been calculated. Estimates indicate that in the region immediately adjacent to the Bolivar sewerage outfall approximately 250 ha have been lost since 1956 (Bayard 1992). In the long-term, continued poor recruitment and increased mortality of mangroves, particularly from St Kilda to Port Gawler, could result in severe reductions in the productivity of these ecosystems. Since the tidal wetlands in this region represent the most important nursery area in Gulf St Vincent for commercial and recreational fisheries (Jones 1984), this problem potentially rivals seagrass degradation in its significance to the State's gulf fisheries.

Considerations for MPAs in South Australia

The size requirement of a viable mangrove forest is unknown but should be considered when zoning or placing protection on mangroves. There is a lot in the literature about size dynamics and the faunal communities that live in mangroves of different sizes, but the viable size of a forest for *Avicennia marina* is not discussed. Because of the size of the forests, the relationship with wetlands behind the mangroves and the biodiversity they contain, mangroves in the gulfs and at Ceduna should be protected.

To determine if human interventions in conservation of mangroves is having any effect the detailed mapping that has been carried out should be used and monitoring programmes initiated. The earlier maps are not useful in measuring small changes in density or coverage of mangroves. Monitoring should take the form of detailed mapping and permanent quadrats established to answer specific questions on the success or otherwise of human intervention, including in MPAs. Sensitive areas of mangrove trees in MPAs should be zoned to prevent disturbances that will impact on them. A widespread educational program to alert the public to the importance of mangroves as nursery areas for fish, protection of the coast and habitat to birds should be initiated. From this knowledge support for zoning and protection of mangrove will be gathered.

In other parts of the world mangroves known to be important for various endangered or threatened species and for goods and services they provide; are protected to varying degrees of success.

Barnacles on pneumatophore.
(Photograph: Sarah Bignell)

Conclusion

Mangroves grow in many parts of the coast of South Australia. The forests have an important role in sustaining biodiversity and physical protection of the coast as follows:

- Support a rich diversity of plant and animal species.
- Protect vulnerable coast lines from storms
- Are the nursery grounds for some commercial and recreational fish and crustacea.
- Recycles nutrients introduced from land-based sources
- Can grow in waterlogged anaerobic and sulphide rich soils

Mangroves are represented by only one species in South Australia with the main threat to them being reclamation of the land on which they grow. The role mangroves play in release of detrital matter and protection from storms gives them a close relationship to seagrass meadows and offshore sand and mudflats. They support many waterbirds and stabilise coastal sediments. The solution to protecting the coast from natural hazards needs to be at the whole catchment scale. Bioshields, including mangroves, provide important ecohydrological services such as creating self-scoured navigable channels, sheltering coastal seagrass beds and reefs from excess sedimentation and enhancing fisheries. These are all resources that the human population living along South Australian estuaries and coasts rely on for their livelihood and quality of life.

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Pelagic Habitats

Catherine Kemper[1] and Charles Huveneers[2]
[1]South Australian Museum
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Pelagic habitats and the physical processes that ultimately define them are represented in South Australian gulf and inshore continental shelf ecosystems. Many species of the migratory megafauna traverse and use these spatially and temporally dynamic habitats on their way to and from our State, so it is important to have a clear understanding of the oceanography and pelagic ecology of this region.

This overview pays special attention to the megafauna that inhabit the pelagic habitat because they are high-profile species, they are generally near the top of the food web, and are often more susceptible to the major anthropogenic threat (e.g., fishing) than most teleost species. Other potential threats to species that use the pelagos include chemical and industrial pollutants, noise pollution, mining, oil and gas exploration (Game *et al.* 2009).

Marine megafauna are here defined as Chondrichthyes (sharks, rays, skates and chimaeras), pinnipeds (seals and sea lions), cetaceans (whales and dolphins), seabirds (e.g., albatrosses and petrels), and turtles. These groups are not only important in an ecological sense but are high profile and therefore valued by the human community. Hoyt (2005) listed three reasons why it is important to consider whales and dolphins when designing marine protected areas: 1) their habitat needs have hitherto been neglected, 2) there is now more information than ever before on cetaceans and 3) cetaceans need large conservation areas so this may be the key to protecting ocean habitats and large new areas. The above reasons can also be connected to other marine megafauna such as pinnipeds and elasmobranchs.

Bottlenose dolphin
(Photograph: MLSSA)

Description/Definition

The marine pelagic environment is the largest realm on Earth, constituting 99% of the biosphere volume (Angel 1993). In addition to supplying >80% of the fish consumed by humans (Pauly *et al*. 2002), pelagic ecosystems account for nearly half of the photosynthesis on Earth (Field *et al*. 1998), thus directly or indirectly support almost all marine life.

It is helpful to define some of the common terms used when describing the ‘Pelagia’ since these are often confused. For example:

Neritic:	Inhabiting the sea over the continental shelf, i.e. coastal waters to about 200 m depth
Oceanic:	Pertaining to the open sea, beyond the continental shelf
Pelagic:	Pertaining to the open sea, including neritic and oceanic waters
Continental slope:	The steep seaward face of a continental shelf, averaging about 4º from the vertical

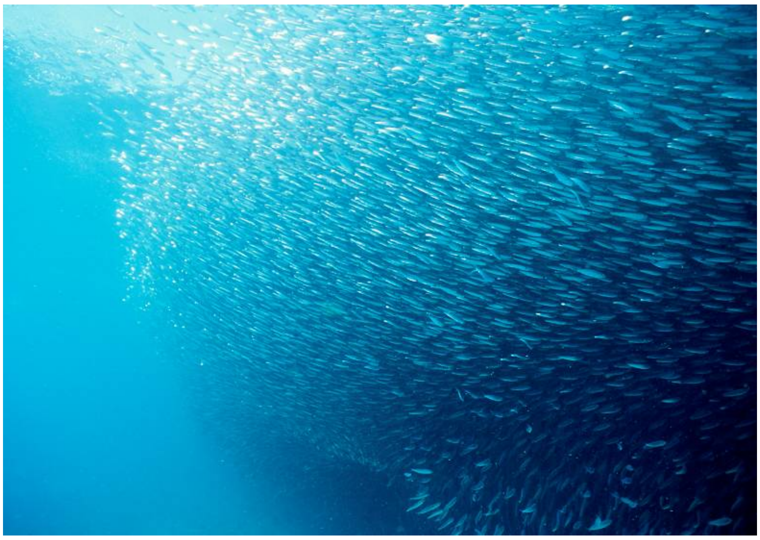
By the above definitions, the waters of the South Australian gulfs are therefore pelagic but they are also protected by Eyre, Yorke and Fleurieu Peninsulas and Kangaroo Island. This makes them quite unique in the Australian context, and for this reason they warrant special conservation status.

Some terms used to describe where organisms live in the pelagic environment are:

Epipelagic:	Living in the upper, sunlit level or epipelagic zone of the oceans (from the surface to about 200 m deep).
Mesopelagic:	Living in the twilight zone below the epipelagic zone where little light penetrates (from 200 to 1,000 m).
Bathypelagic:	Living in the sunless zone below 1,000 m extending to the deep slopes rises, ocean floor and trenches (down to 6,000 m or more).
Semipelagic:	Penetrate oceanic waters but concentrate close to continental landmasses over continental slopes and rises.
Demersal:	Living near the sea floor.
Benthic:	Living on the sea floor.

Marine megafauna may use several zones of the water column.

Oceanic waters are generally less productive and contain less biomass and less diversity than coastal waters. Nevertheless, there are also 'hotspots' of relatively high productivity and biodiversity in the open ocean, generally associated with nearby bathymetric structures, such as seamounts and mid-ocean ridges, and oceanographic features including, eddies and sea-surface temperature defined frontal zones (Worm *et al*. 2003), whereas pelagic waters can also be influenced by the interaction between landmasses, wind regimes and currents, which can result in upwelling. Areas of high productivity can vary seasonally, or shift with oceanographic conditions, so it can be necessary for pelagic organisms to migrate long distances (Block *et al*. 2001).



Sardines; a food source of many pelagic species.
(Photograph: Marine themes.com/Kelvin Aitken)

South Australian (SA) marine waters fall within the temperate to warm temperate zone where sea surface temperatures (SST) are about 10–20ºC. For the most part, water temperatures range 14–23ºC, with 10ºC being rare at the surface (Figure 5). Oceanographic features, such as currents and upwelling affect coastal and southern gulf conditions. The Leeuwin Current is a warm water mass that flows southward along the Western Australian coast and into the Great Australian Bight during early winter. It is variable in strength and the eastward extent to which it flows varies from year to year (Feng *et al*. 2003) and this may influence how far east it penetrates the SA region. In some years, the Leeuwin Current can reach as far east as Tasmania. It is likely that some vagrant tropical and subtropical marine fauna (e.g. turtles, Bryde's whale, pygmy killer whale) make their way to SA waters in this current (Maxwell and Cresswell, 1981, Segawa 2009). During the summer, the Flinders Current flows along the continental slope at around 600m depth from the west coast of Tasmania. This deep-water current drives cold water onto the shelf where it can be brought to the surface via wind driven upwelling. One of the major drivers of the ocean systems to the south of Australia is the Westwind Drift (Tomczak and Godfrey, 1994). However, during winter, an easterly flowing counter-current appears over the flow of the Flinders current and pushes it deeper (

Figure 5).

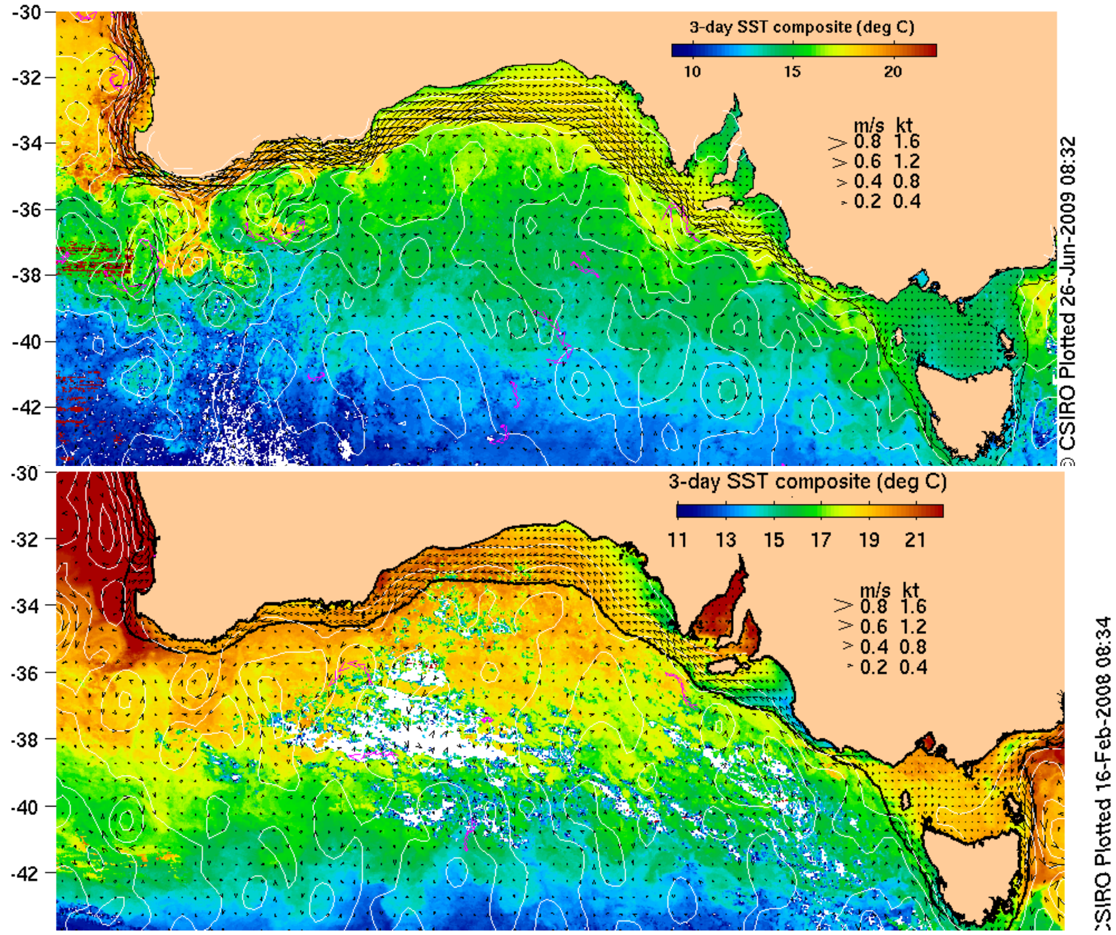


Figure 5. Sea Surface Temperature from 3-day composite image. Top figure represents typical winter condition with eastward flowing coastal current and strong Leeuwin current. Bottom figure represents typical summer/autumn condition with westward flow and strong upwelling in the Southeast of South Australia. Image © CSIRO.

The upwelling systems that are found on the continental shelf off SA may be the most important in Australia (Kampf *et al*. 2004). As discussed in the chapter on upwellings, the Bonney Upwelling occurs off the Limestone Coast in Southeast SA from about November to April and may have a major influence on the vertebrate fauna of the region (Middleton and Bye 2007). This upwelling represents the most biologically significant seasonal oceanographic feature in the SA marine region and occurs over a narrower part of the shelf than those that occur in the GAB. The upwelling region is used by a suite of large migratory species both during the peaks of the upwelling and in the periods directly following the events. For example, pygmy blue whales are present and feed on krill in the upwelling system (Gill 2002) and there is evidence that some other baleen whales (pygmy right whales, Gill *et al*. 2008) may also take advantage of the zooplankton blooms. Other highly migratory species that use this pelagic foraging area include small pelagic (e.g., sardine, anchovy) and large pelagic fish species (e.g., southern bluefin tuna, albacore), sharks (white sharks, shortfin mako), pinnipeds (e.g., New Zealand fur seals, Australian sea lions), and birds (e.g., wondering albatross, Australasian gannets, little penguins) (Goldsworthy *et al*. 2011).

Flow-on effects of increased productivity as a result of upwelling are likely to be advantageous for other marine vertebrates. For example, 86% of the Australian sea-lion population is found in SA waters (Goldsworthy *et al*. 2009). Two smaller regions of upwelling are found west of Kangaroo Island and west of southern Eyre Peninsula (McClatchie *et al*. 2006; van Ruth 2009). Productivity there is inter-annually variable (van Ruth *et al*. 2009) and may influence the presence/abundance of marine vertebrates using this region as a pelagic foraging area. (Kemper and Ling 1991, Shaughnessy *et al*. 1994).

The Subtropical Front (Convergence) lies between 39 and 49 ° S (Belkin and Gordon 1996) and is also an important nutrient-rich zone. Some species of whales are known to feed in this region (Kawamura 1974) and there is evidence that New Zealand fur seals forage across this broad area (Baylis *et al.* 2008, Page *et al*. 2006). The position of the Front is variable in its latitudinal position and in some years may be responsible for the irregular appearance of subantarctic species along the SA coast.

The continental slope, Murray Canyons and Ceduna Canyons are features of steep gradients in water depth. Deep sea fish and squid that inhabit these areas are the prey of sperm whales and beaked whales that are sometimes recorded (alive or dead) in coastal waters (Kemper and Link 1991).

There are far fewer species of elasmobranchs (sharks and rays) in the open ocean than in coastal waters, these species are wide-ranging and play an important role in the food webs of the high seas. Of the roughly 1,160 extant species of elasmobranchs fishes, 26–31 species (about 2.5%) are oceanic, spending much of their life in open ocean waters away from continental landmasses, while an additional 2.8% are semipelagic (Compagno 2008).

Threats

Pelagic ecosystems face a multitude of threats including overfishing, pollution, climate change, eutrophication, mining and species introductions (

Figure 6). These threats can act synergistically and can fundamentally alter pelagic ecosystems (Game *et al*. 2009).

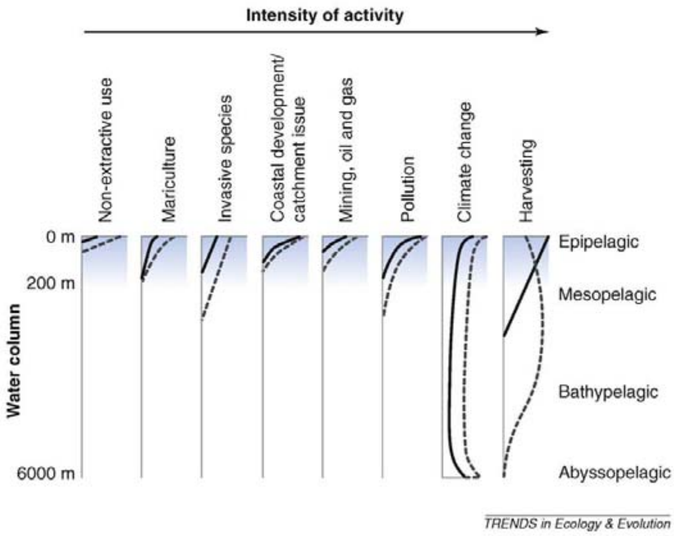


Figure 6. Schematic of the intensity of the eight largest threats in the pelagic ocean as a function of depth. Blue shading indicates the penetration of light (euphotic zone) into the water column. The solid line is the current intensity of these threats, while the dashed line indicates the potential change in intensity over the next 50 years (generally increasing and moving deeper). This figure is reproduced from Game *et al.* (2009).

Mechanisms that threaten the conservation of the pelagic habitat and associated organisms are poorly understood because of the often-remote nature of this environment. Many of the examples listed below apply to sharks and marine mammals but can equally be relevant for other fauna, including other vertebrate megafauna. An in-depth discussion of the threats to Australian cetaceans is found in Bannister *et al*. (1996), to pinnipeds in Shaughnessy (1999) and Goldsworthy *et al*. (2009), and to chondrichthyans in Camhi *et al*. (2007, 2008). Immediate threats involve processes that result in mortality and serious injury, intermediate and long-term threats are those that are more subtle and may take more time to show an effect on marine mammals.

Pelagic shark species exhibit a wide range of life-history characteristics, but many have relatively low productivity and consequently relatively high intrinsic vulnerability to threats such as over-exploitation (Dulvy *et al*. 2008). Overall, 32% of the world's pelagic sharks and rays are threatened. As a group, pelagic elasmobranchs suffer significantly greater threats than do elasmobranchs as a whole (Camhi *et al*. 2009).

Immediate Threats

Commercial fishing including longline, purse seines and gillnets has been identified as the single most important threat to pelagic chondrichthyans wherever they occur. Oceanic shark and ray species taken regularly in high-seas fisheries (e.g., shortfin mako) are more likely to be threatened (52%) than are pelagic elasmobranchs in general (Camhi *et al*. 2009). Pelagic sharks occur in international waters and most migrate across national borders. Because they move regularly between the EEZ's of different countries and into the high seas, they do not fully benefit from regulations that apply only to the waters or fleets of a single country.

Immediate threats to marine mammals include illegal killing (all marine mammals are protected in Australian waters under the *Environmental Protection and Biodiversity Conservation Act 1999*), incidental catch, vessel collisions, pollution in the form of plastic and other debris, and entanglement. Illegal killing of dolphins (Kemper *et al*. 2005) and pinnipeds has been recorded in several regions in the state (SA Museum, unpublished data), including Gulf St Vincent, lower Spencer Gulf and south of Kangaroo Island. Incidental catch (bycatch) is a documented and serious concern for Australian sea-lions in the demersal shark fishery in four areas: off Ceduna, off Port Lincoln, south of Kangaroo Island and south of the Fleurieu Peninsula (Goldsworthy *et al*. 2009; Goldsworthy *et al*. 2010) and for short-beaked common dolphins in the SA Sardine Fishery in lower Spencer Gulf and Investigator Strait (Hamer *et al*. 2008). Bycatch of bottlenose dolphins has also been recorded in the sardine fishery but the degree of threat is not known. If offshore finfish aquaculture is established in SA, there is potential for entanglement of cetaceans and pinnipeds since this has been documented in coastal areas (Kemper and Gibbs 2001). Entanglement of large cetaceans in SA is documented for southern right whales (Kemper *et al*. 2008) and sperm whales (Shaughnessy *et al*. 2003) and there is one case of a humpback whale trapped in a tuna cage near Port Lincoln (Kemper 2005). In the pelagic environment, longlines are probably the most common form of recorded entanglement of large whales. Monitoring fatal entanglements in SA (both in the coastal and pelagic environment) is difficult because, although there is a requirement to report incidents, there is no co-ordinated approach by government agencies. Mortality of Australian sea-lions has been reported in rock lobster pots and there is potential for considerable interaction in three areas of the State: off Streaky Bay, south of Eyre Peninsula and south of Kangaroo Island (Goldsworthy *et al*. 2009).

Australian Sealion, KI
(Photograph: Robyn Morcom)

Fatal vessel collisions are documented in SA for the southern right whale (Kemper *et al*. 2008), dolphins (Kemper *et al*. 2005), sperm whale, fin whale, Antarctic minke whale and pygmy right whale (SA Museum, unpublished data). Collisions involving large vessels are more likely to occur in the ship corridors between Melbourne and Adelaide and Adelaide/Melbourne to Perth. At present these routes are not as heavily used as along the eastern seaboard of Australia and therefore not considered a serious threat to large cetaceans but many collisions are likely to go unreported.

Intermediate Threats

Intermediate threats to vertebrate megafauna include competition from commercial fisheries, the less immediate effects of oil spills, disturbance and harassment, degradation of habitat, and exposure to human and domestic animal diseases. There is now a reasonable knowledge of the diet, feeding locations and population size of the Australian sea lion and a concern for overlap with the demersal gillnet fishery for sharks (Goldsworthy *et al*. 2009). For all species of cetacean living in SA, there is inadequate data on diet, feeding areas and population size to comment on these threats except to say there is some overlap in species harvested by humans and consumed by toothed whales and dolphins (Kemper and Gibbs 2001). There is potential that harvesting sardines may impact short-beaked common dolphins through resource competition.

Exploration for petroleum and gas are being undertaken in the SE of SA, the Great Australian Bight and to the west of Kangaroo Island. Oil exploration usually involves seismic surveys which may affect some marine mammal species (Richardson *et al*. 1995). If adequate reserves are found and mining commences, the benthic zone and other layers of the water column will be affected in localised areas. Oil spills are a substantial risk in the pelagic environment and marine mammals (Geraci and St Aubin 1990), even with tight controls on mining processes. There are no documented cases of oil spills in pelagic waters of SA but there is potential for serious consequences to the Australian sea-lion and New Zealand fur-seal if oil washes up in the vicinity of many breeding colonies around Kangaroo Island and the south and west coast of Eyre Peninsula (Shaughnessy 1999). In the event of a substantial oil spill, the effects on calving grounds of southern right whales (e.g. Head of Bight, Sleaford Bay, and Encounter Bay) are likely to be serious.

***Megaptera novaeangliae* (humpback whale) with calf.**
(Photograph: Aude Loisier)

Bottom trawling impacts benthic fauna and flora through alterations, sometimes recurrent, to the ocean floor. There are commonwealth deep water bottom trawlers that operate in the Great Australian Bight, while three South Australian prawn trawlers operate in inshore waters (~10-50m) between Ceduna and Coffin Bay. State prawn trawl fisheries also operate within Spencer Gulf and Gulf St Vincent. South Australian prawn fisheries operate within a management framework that restricts fishing both spatially and temporally to maximise economic returns and reduce impacts. For example in Spencer Gulf, fishing generally occurs for ~50 nights of the year, with >90% of the catch trawled from ~20% of the available fishing area (generally waters >10m).

Exposure to infectious human and domestic animal diseases is likely to be more concern in the coastal habitats and associated fauna. However, pathogens could spread to pelagic habitats. No outbreaks of morbillivirus have been reported in Australian waters and there have been no mass mortalities as a result of disease. The potential exists for a variety of diseases to be spread by 'rescued' and released pinnipeds, a practise that is currently being carried out in the State. Although the South Australian Museum performs necropsies on marine mammals opportunistically collected during grant-funded research, there is no recognition by the South Australian Government that routine sampling should be carried out in order to monitor disease outbreaks.

Long-term Threats

Except in cases of acute toxicity, chemical pollution and marine debris are long-term threats for marine megafauna. For example, heavy metal pollution from the Port Pirie smelter is a known threat to Spencer Gulf and possibly beyond (through water circulation and movement of organisms) and there are documented cases of high levels of zinc, lead and cadmium in sediments, fauna and flora, particularly from upper Spencer Gulf (Lavery *et al*. 2008). Heavy metals accumulate in the tissues of long-lived vertebrates and can cause a range of deleterious effects, including bone disease in dolphins from Spencer Gulf (Lavery *et al*. 2009). Much of the pelagic environment of SA is remote from industrial pollution (e.g. Great Australian Bight) and this threat is not generally considered a concern. However, there may be far-ranging effects from pollutants due to water movement in currents, both surface and deeper layers. For example, it is known that the heavy, salt-laden (and presumably contaminated with heavy metals) water takes about 1 year to travel from the head of Spencer Gulf to Investigator Strait (Nunes and Lennon 1986).

There is little information on the extent of floating debris in South Australia. A project is currently underway to document marine debris in Gulf St Vincent bioregion and Kangaroo Island (through a 'Caring for our Country' grant to the Adelaide and Mount Lofty NRM Board) and there are published data on the west coast of Eyre Peninsula. Entanglement rates for Australian sea lions and New Zealand fur seals in South Australia are reported as amongst the highest in the world for pinniped species (Page *et al*. 2004).

Other long-term threats include the reduced genetic variation in depleted populations. Such a scenario may apply to Australian sea lions, New Zealand fur seals, southern right whales and other 'great whales' because these species were substantially reduced by hunting in the 19th and 20th centuries.

The effects of climate change on the marine megafauna are not known. The likely scenarios include altered distributions of species as a result of higher sea levels, warmer water and changes in upwelling patterns. There may be deleterious effects on species already vulnerable or endangered, e.g. Australian sea lion, blue whale.

For some species, long-term threats may include resource competition from other marine megafauna. For example, the New Zealand fur seal is increasing at rates of about 11.2 % per annum (Shaughnessy *et al*. 2009). The overall trend for the Australian sea lion is not known: numbers are increasing at Dangerous Reef, stable at The Pages and decreasing at Seal Bay (Goldsworthy *et al*. 2009).

Vulnerability

South Australian waters include pelagic environments primarily in Spencer Gulf, Gulf St Vincent, Investigator Strait and around offshore islands. These will be the focus of the discussion below although it should be recognised that areas along the open ocean coast are considerably influenced by the nearby pelagic habitat. Emphasis is placed on species either listed as threatened (*EPBC Act*) or for which there is concern for their long-term future.

Great white shark
(Photograph: Marinethemes.com/Mark Conlin)

The pelagic and semipelagic shark species which occurred in South Australian waters include the thresher shark, bigeye thresher, white shark, shortfin mako, blue shark, porbeagle shark, school shark, bronze whaler, dusky whaler, scalloped hammerhead, and smooth hammerhead. The whale shark, basking shark, oceanic whitetip shark, and goblin shark are also pelagic species known to occur in South Australia but have only been observed on rare occasions. The IUCN listing of the regular species of pelagic sharks highlights the vulnerability of these species with 82% listed as globally Threatened and the remaining listed as Near Threatened. According to a report determining the vulnerability of over-exploitation of pelagic sharks, the South Australian species at the highest risk are the bigeye thresher and shortfin mako. The porbeagle and common thresher were grouped and identified as having the next greatest risk.

The pelagic habitats found in Gulf St Vincent, Investigator Strait, Backstairs Passage and Spencer Gulf are unique in Australia and likely to be more affected than other parts of the State simply because there are so many human activities in the gulfs. In addition, they are shallow, protected bodies of water which have limited exchange with the oceanic environment and therefore there is potential to accumulate pollutants. The waters of Investigator Strait are important because they represent an ecotone between the gulfs and the pelagic habitat of the Southern Ocean. As such it contains a diverse mix of inshore and offshore species. A dolphin survey in 2005 detected many more dolphins south and east of the tip of Eyre Peninsula compared to within Spencer Gulf (Kemper *et al*. 2006).

Megafauna species that are most affected by human activities are those that are resident in the gulfs (e.g. Indo-Pacific bottlenose dolphins, possibly short-beaked common dolphins and whaler sharks) as opposed to those that are seasonal visitors (e.g. southern right whale, humpback whale, shortfin mako). The Australian sea lion can be found throughout the gulfs but breeding colonies are at the southern end of the gulfs, near the open ocean environment.

The coastal waters from Kangaroo Island to the Victorian border are rich in marine life because of the nearby Bonney Upwelling. Pelagic species of whales, dolphins and sharks frequent the region and may come closer to shore than elsewhere in the State, in part because the shelf is relatively narrow. Upwelling is also important in the area south of Eyre Peninsula and west of Kangaroo Island (McClatchie *et al*. 2006). This factor may explain the numerous cetacean strandings (Kemper and Ling 1991), and the abundance of Australian sea lion and New Zealand fur seals (Shaughnessy *et al*. 1994, Goldsworthy *et al*. 2009) in that region. In addition to the enhanced nutrients as a result of upwelling, the region is close to the edge of the continental shelf where pelagic species are frequently encountered.

Considerations for MPAs in South Australia

Because pelagic systems are not static on the same scale as most benthic marine habitats, the use of protected areas to help mitigate threats to pelagic biodiversity represents a departure from conventional thinking regarding their utility. Whereas there is no question that protected areas will be neither the best nor only required response to some threat, well-selected pelagic MPAs can directly or indirectly help address the threats addressed in the previous section of this document. For entirely anthropogenic threats such as harvesting, mining or non-extractive use, MPAs can result in direct localised abatement. Through a reduction in cumulative impact, MPAs can also help mitigate the severity of threats where direct abatement is not possible (Hooker *et al*. 2004).

The below pelagic areas have been identified and listed in order of perceived importance based on relative ecological importance and predictability of oceanographic features, abundance and diversity of threatened species of pelagic predators in these areas, and habitat/bathymetric complexity.

1. Southeast SA (Bonney upwelling system) during summer and autumn.
2. Great Australian Bight (during spring–autumn and early winter in some years)
3. Central Gulf St Vincent and Spencer Gulf
4. Lower Eyre Peninsula (this upwelling is relatively small and sporadic and really only stretches from to Pt Sir Issacs to Liguanea Is) (spring–autumn)
5. Investigator Strait
6. West Coast (most of the pelagic productivity is out on the slope so not really relevant to this planning process)
7. South coast of Kangaroo Island (spring–autumn)
8. South Australian shelf edge

Southeast South Australia (Bonney upwelling): The continental shelf in this region is particularly narrow. This characteristic in association with strong Southeast trade winds in summer and autumn months creates strong upwelling events (Bonney Upwelling). As a result, many truly pelagic small pelagics (e.g., jack mackerel, redbait blue mackerel, arrow squids), large pelagics (e.g., Southern bluefin tuna), sharks (e.g., shortfin mako, blue, thresher), and cetaceans (e.g., blue whale) have been recorded in the area. The influence of the Bonney Upwelling on the surrounding ecosystem, and the abundance and diversity of marine megafauna is considerable.

Great Australian Bight: The seasonal upwelling boosts primary, secondary and fish production, making the Eastern GAB Australia's richest pelagic ecosystem, and an ecological 'hot-spot' of international significance. The region supports the highest densities of small pelagic fishes in Australian waters. These rich pelagic resources also underpin arguably the greatest density and biomass of apex predators to be found in Australian coastal waters. These include marine mammals such as pygmy blue whales, and >80% of Australia's populations of New Zealand fur seals and Australian sea lions. Other key apex predators include seabirds, such as short-tailed shearwaters (~1.3 million pairs breed in the eastern GAB), little penguins and crested terns; pelagic sharks including bronze and dusky whalers, white sharks, and shortfin mako; and predatory fishes such as southern bluefin tuna.

Central Gulf St Vincent and Spencer Gulf: The gulfs are oceanographically and geographically unique in Australia, in part because they are inverse estuaries. It is important that not just the coastal parts of the gulfs be conserved.

Lower Eyre Peninsula (including Coffin Bay): One of the important upwelling systems for South Australia occurs in this region. Stranding records show that it is a hotspot for diverse range of cetacean species (Kemper and Ling 1991). It includes major breeding colonies of the

Australian sea lion and New Zealand fur seal, which are also areas where white sharks often occur. It is an area frequented by many species of pelagic sharks (e.g., white sharks, whaler sharks, blue shark and shortfin mako) which interact with the aquaculture industry (Murray-Jones 2004).This region also encompasses the Neptune Islands, which is considered the largest aggregation of adult white sharks in Australia, and is a breeding area for New Zealand fur seals, Australian sea lions and short-tailed shearwaters.

Investigator Strait: This area is important for both inshore and pelagic marine megafauna (Kemper *et al*. 2008) and is the ecotone between the gulfs and the Southern Ocean. It is likely to be an important corridor for many forms of marine life. A strong frontal system is found near the entrance to Spencer Gulf and this enhances nutrient exchange.

Mako shark
(Photograph: Andrew & Rodney Fox)

West Coast: This area is adjacent to the pelagic environment of the wide shelf of the Great Australian Bight, a unique feature on the southern coast of Australia. It includes one of the likely migration routes for white sharks, shortfin makos, and southern right whales and a potential hotspot for the pygmy sperm whale in Australia. The influence of the Leeuwin Current may result in subtropical and tropical fauna appearing from time to time in the region.

South Coast of Kangaroo Island: Like the Lower Southeast of SA, this region is important because it has a narrow continental shelf and abuts the true force of the Southern Ocean. In addition, the Cape De Coudic and Murray Canyons are nearby and believed to support a diverse faunal community, including sharks and cetaceans. Furthermore, recent tagging studies suggest that shortfin makos are often associated with the shelf canyons and the seamounts located south and southeast of Kangaroo Island, respectively.

South Australian shelf edge: Several tagging studies (Bruce *et al*. 2006; Rogers, unpublished data) have found that the shelf edge is commonly used as migratory routes for pelagic species such as white sharks and shortfin makos. Although it is outside State waters but in Commonwealth waters, the shelf edge is likely to be an important pelagic habitat for many species such as tunas, sharks, and cetaceans.

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Rhodolith habitats

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Description

Rhodoliths are mobile, free-living forms, as opposed to encrusting forms, of coralline algae, that roll about on shelly bottom or on sediment, sometimes among seagrass beds of *Amphibolis* or *Posidonia*, and form a unique habitat that has features of both hard and soft bottoms. Areas of seabed dominated by them are called rhodolith beds. Some 26 genera of crustose corallines are recognised, and at least 8 of them contain species that form rhodolith beds (Woelkerling 1996; Harvey & Woelkerling 2007; Harvey & Bird 2008). Rhodolith beds develop from crustose algal spores settling onto small grains of sand or gravel, or from broken pieces of coralline nodules.

In southern Australia five main rhodolith-forming genera have been recorded, *Lithothamnion, Hydrolithon, Mesophyllum, Neogoniolithon,* and *Sporolithon*, and they have a similar variety of forms as the encrusting corallines forms, i.e. warty, lumpy, fruticose etc. Rhodoliths often occur in high densities and form deposits of living and dead aggregations, comprising one to five or so species. Rhodoliths are rolled about by water currents and swell, and Foster (2001) has colourfully called them the “calcareous tumbleweeds of the sea”, forming “reefs which rock and roll”. Some commercial fishers call them ‘popcorn’.

Rhodoliths amongst mixed algae in shallow water, lower southeast.
(Photograph: Sarah Bignell)

After a bed is established, recruitment is probably mainly by breakage and overgrowth. Rhodoliths grow extremely slowly, according to the sparse data available, and growth rates in temperate waters are typically 0.2-0.6 mm yr^{-1} in depths <20 m, and much lower (0.01-0.1 mm yr^{-1}) in deeper water (Foster 2001; Steller *et al*. 2007).

The longevity of rhodoliths is known for only two species in southern Australia. Shallow-water nodules of *Sporolithon durum*,7-9 cm diameter and living at 1-3 m depth at Rottnest Island, Western Australia, were aged by radiocarbon dating at <60 years old (Goldberg & Heine 2008). Deep-water forms at 38 m depth, with a size range of 2-6 cm, from a rhodolith bed in Esperance Bay, Western Australia, were found to range widely in age from modern (<50 years old) to ~960 years. As rhodoliths can grow uninterruptedly for more than 100 years, it is likely that the older ones became buried, died, and later exposed and recolonised (Goldberg 2006). The growth and longevity information available suggest that established beds, especially in deeper water, are likely to be decades to many centuries old.

Distribution

Rhodoliths have strict habitat requirements. They are found mainly on sediments with a high calcareous content, and usually where shell, or gravel, or cobbles also occur. Carbonate production is high on the southern Australian shelf (see James *et al*. 1992, 1994, 1999), and favours rhodolith development, as shown in Esperance Bay, where calcium carbonate comprises 83% of the sediment (Ryan *et al*. 2007), and rhodolith beds cover 14% of >1000 km^2 of mapped bottom habitats (Baxter *et al*. 2005). Rhodoliths also require moderate water movement. If water movement is too low, they become buried by sediment, and if too high, they are rolled or carried away. The degree of water movement also affects the shape and branching patterns of rhodoliths, with spherical shapes favoured by moderate water movement, and irregular shapes by lower water movement (Foster 2001).

Rhodoliths taken at 77 m in the eastern Great Australian Bight. (Photograph: Shirley Sorokin)

Rhodolith beds are found sparsely throughout southern Australia, but this sparsity may partly be an artefact of the patchiness of bottom surveying, and the depths of offshore beds. They have been recorded down the west Australian coast, notably on the Rottnest Shelf at 35-60 m depth (Collins 1988; James *et al* 1999). In the western Great Australian Bight (GAB), they were recorded in Esperance Bay, at depths of 27-65 m (Goldberg 2006). Beds are extensive among islands of the Recherche Archipelago, where they are found mainly at depths of 27-65 m in waters open to the swell (Harvey *et al*. 2004) and at 30 m depth off Twilight Cove, 430 km NE of Esperance Bay, (H. Kirkman pers.comm.). East of Israelite Bay in the NW GAB, the Roe Shelf extends for 100 km offshore from the Baxter Cliffs, and supports beds of small to cobble-sized rhodoliths to ~5 cm size at depths of 35-60 m; they were described as ‘compact to rounded, branching or dendritic’ (James *et al*. 2001).In the NE GAB they are found at 60-135 m depth (James *et al*. 1994, 2001; S. Sorokin pers. comm.). On the Lacepede Shelf, SE of KI, they were recorded at 60-80 m depths (James *et al*. 1994), and also in near-shore waters off Port MacDonnell, South Australia (Harvey & Bird (2008), off Ocean Grove, western Bass Strait at depths of 30-35 m (S. Chidgey pers.comm.), and in deeper shelf waters of eastern Australia (Marshall & Davies 1978).

The exposed southern Australian coasts are subject to prevailing swells of 10-16 s period and wave lengths of up to 200 m. These swells penetrate to >100 m depth (rarely to 160 m depth), and produce bottom orbital velocities of 50 cm s^{-1} (see Goldberg 2006)-an oscillatory motion more than enough to rework and sort the sediments. The depth range of 60-80 m on much of the southern exposed coast, and slightly shallower depths where swell is attenuated by coastal topography, are apparently optimal for rhodolith beds; however fragments of living rhodoliths are likely to be found in depths down to 240 m, as on the Lacepede Shelf, SE of Kangaroo Island (KI) (James *et al*. 1992).

In Gulf waters, rhodoliths also seem very patchy. In bays and gulfs the distribution of rhodoliths seems to be controlled by tidal movement or by wind-driven waves. Short-period waves of ~1 m high are able to move rhodoliths at 5 m depth, and tidal currents of 30 cm s^{-1} can roll or rock them, depending on the complexity of their shape (Marrack 1999; unpublished observations). Hence rhodolith beds in Spencer Gulf are located in places of moderate tidal current. Periodic rotation of nodules appears necessary for light to reach all sides of the nodule, as well as to prevent burial or fouling.

Svane *et al*. (2009) recorded rhodoliths as present in Spencer Gulf at depths of 20-25 m in places of moderate to strong tidal current, as shown in (Figure); other records further south in Spencer Gulf are NE of Corny Point at 20 m depth (K. Rowling pers. comm.), and in beds off Pt Bolingbroke, near Port Lincoln, SW Spencer Gulf at 19 m (S.Fraser pers. comm.). In Investigator Strait rhodoliths are abundant at 20 m depth south of Troubridge Pt.

In shallow bays rhodoliths have been recorded in Proper Bay, Port Lincoln at depths of 3-4 m on a rubbly, limestone bottom (Shepherd 1975) and (as *Lithothamnion erubescens*) by Womersley (1956) in Pelican Lagoon, Kangaroo Island at <1 m depth. Harvey & Bird (2008) recorded an extensive rhodolith bed over 1 km^2 in size at the entrance to Western Port, Victoria at a site with moderate tidal currents. The bed comprised five common species, and averaged ~500 rhodoliths m^{-2}, of which up to two thirds were dead. Rhodoliths have also been recorded from numerous bays in eastern Australia, from Gabo Island north to Byron Bay (Harvey *et al*. 2002), but no further details are known.

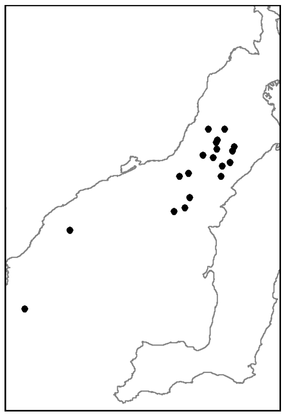


Figure 8. Rhodolith (*Sporolithon durum*) recorded from Spencer Gulf, with distribution map of records (extracted from Currie *et al*. 2009).

Function

The production rates of rhodolith beds in temperate waters have been shown to be surprisingly similar to those for coral reefs. Typical rates are in the range 200 – 1200 g $CaC0_3$ m^{-2} yr^{-1} (review of Bosence & Wilson 2003). Such rates can cause beds to accumulate at a rate of ~1 mm yr^{-1}, though thick beds (to 1 m) have so far only been recorded in the western Great Australian Bight.

Rhodoliths have been called foundation species or 'bio-engineers', because they modify benthic habitats by providing hard surfaces for some species and shelter in their interstices and between nodules for others (Steller *et al*. 2003). Larger nodules, and those with higher branch density, support greater faunal densities than smaller or simpler ones (Steller *et al*. 2007). The Western Port rhodolith beds are dense, with an average of ~500 nodules m^{-2}, and Harvey & Bird (2008) measured the cryptic fauna living within the branches of the rhodoliths. The rhodolith habitat contained an average density of 400 individuals L^{-1} (of rhodolith volume) living in their interstices, comprising 89% polychaete worms, 8% bivalves and the remainder echinoderms and crustaceans.

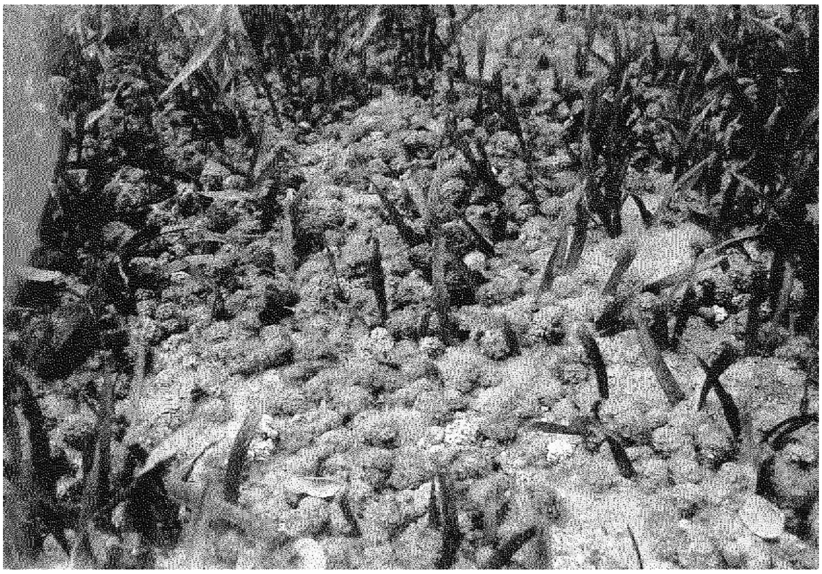
Rhodolith bed at site with strong tidal current at 19 m depth off Point Bolingbroke, SW Spencer Gulf. (Photograph: S. Fraser)

In another study by Mathis *et al*. (2005) of the fauna in the Esperance rhodolith beds, the average density of fauna living on the rhodoliths (the epifauna), and those nestling in the interstices between the warts or lumps of nodules, as well as those living in tubes or galleries within the nodules (the endofauna) averaged 1250 individualsL^{-1} (of rhodolith volume) excluding protists. About 62% of these lived in the interstices between nodules, and the rest lived on the surface (the epifauna). Polychaetes, with 59% of the total, were the most common group, followed by bryozoans (16%), arthropods (9%), sponges (6%), and ascidians (5%), with small numbers of hydroids, echiurans, sipunculans and bivalve molluscs.

These and other studies show that faunal species' richness is almost twice as high, and density a thousand times higher in rhodolith beds compared with sandy bottom. The reason for such a huge difference is that the fauna of rhodolith beds includes many species requiring a hard substrate e.g. sponges and ascidians, as well as (a) species that live in the spaces between rhodoliths, (b) those that are interstitial in branching rhodoliths and (c) predators.

Threats

Rhodolith beds have very low resilience to bottom trawling, due to their slow growth rates, and the negative and fatal impact of burial. Trawling is the severest form of human disturbance that initially reduces rhodolith density and size, and ultimately degrades them structurally to a gravel bottom (Kamenos *et al*. 2003; Steller *et al*. 2003). Other threats to rhodolith beds are: turbidity and sedimentation from terrestrial run-off, as in Western Port (Harvey & Bird 2008); organic enrichment from fish farms; and storm-water or effluent outfalls.



Rhodolith bed of *Lithophyllum* sp. in sparse *Posidonia australis* bed at 3-4 m depth off Billy Lights Point, Proper Bay, Port Lincoln recorded in 1975. (Photograph: Kevin Branden)

Disturbance effects on the fauna living in the beds are as severe as those on the corallines themselves. Besides direct effects resulting from loss of habitat structure, indirect effects, such as declines in fragile and omnivorous species, increase in soft-sediment species and scavengers, and declines in predatory species, also take place. The outcome can be a high loss of species, functional diversity and resource monopolization by a few dominant species (Grall & Glémarec 1997). Another study on the specific effects of fish farms on the fauna of rhodolith beds found serious loss of faunal biodiversity, and particularly abundances of small crustaceans (ostracods, isopods, tanaids and cumaceans) (Hall-Spencer *et al*. 2006).

Vulnerability and recommendations for MPAs in South Australia

Rhodoliths are slow-growing and very long-lived, and their beds form a highly specialised habitat in places subject to appropriate water movement and absence of sedimentation. They can also be highly productive in that they may harbour a species-rich interstitial fauna. A consequence of the increasing threats to rhodolith beds globally, and the recognition of their high scientific and conservation value, is that many of them are protected in European waters (Council of European Communities 1992), and also New Zealand.

So far as is known they are comparatively rare in South Australia. They would be best protected within the MPA framework in Sanctuary or Habitat Protection Zones, to protect them from trawling, and harmful inputs from terrestrial sources. Beds deeper than 50 m are mainly under Commonwealth jurisdiction, but where they might occur in State waters e.g. in lower Gulf waters or around islands in the eastern Great Australian Bight, they should be protected as above.

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Saltmarshes

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Description and distribution

Saltmarshes are usually areas of muddy or sometimes sandy sediments along sheltered coastlines which are often described as 'Coastal Wetlands' on many maps or coastal descriptions. In Australia, saltmarshes do not conform to 'traditional' models of saltmarshes from overseas (which are often dominated by the grass genus *Spartina*). There are saltmarshes distributed around all of the coast of Australia (Saintilan 2009a,b) and they vary geographically in terms of both speciosity (more species in the south than north) and area (more in the north).

In South Australia saltmarshes are composed of several different plant associations including species from the grasses, shrubs, herbs and sedges. As for mangroves we use the term "saltmarsh" to describe both the overall habitat and also the plants that grow there. Unlike the east coast versions, saltmarshes in SA are not mainly confined to estuaries; instead they occupy large areas behind the open coastlines of our sheltered waters such as in the Gulfs. They are also only sometimes found in SA in association with the grey mangrove, *Avicennia marina*, and most of the largest marshes extend well beyond where mangroves can grow.

***Avicennia marina*, RS Saltfields,**
(Photograph: Ron Sandercock)

South Australia is in many ways the centre for saltmarshes in Australia. For example, of the 36 Interim Biogeographic Regionalisation of Australia (IBRA) bioregions, five in SA are ranked 1 to 4 and 13 for the proportion of the national saltmarsh flora (from 37 to 68% of all plant species; see Saintilan 2009b) contained therein. The same author goes on to say that "[t]hree quarters of the 93 listed saltmarsh species grow within 200 km of Adelaide"! Only WA has more species within its State borders but that includes a large tropical component that SA lacks.

The northern parts of the two gulfs in South Australia are the location for vast saltmarshes covering about 15000 ha in the Northern & Yorke NRM region and 6500 ha in the Eyre NRM region (Rumbelow & Speziali 2010). As mentioned previously, our saltmarshes are not confined to estuaries, which is the common perception from the eastern states' experience.

Typically, saltmarsh habitats are only periodically inundated by the highest tides, they grow in sediments or soils that are often waterlogged and extremely saline (with salt concentrations often well above seawater, due to evaporation). The plants that have adapted to such harsh conditions are diverse, coming from at least 25 families and show a convergent set of plant traits even though they are not necessarily closely related. Thus there seem to be only a few ways of living in such harsh conditions. The major plant associations found in our saltmarshes include the samphires or chenopod shrublands (typified by the samphire *Sarcocornia quinqueflora* and other succulents), salt-tolerant grasses (e.g. *Sporobolus virginicus*), sedges (e.g. the genus *Gahnia*) and herbfields (e.g. *Selleria radicans*). These vegetation formations are often separated vertically by only a few centimetres and may represent differences in soil porosity or salinity, to form complex mosaics of plant associations. At their lower points they may abut either mudflats (including those with intertidal seagrasses) or mangroves, whereas at their upper boundaries they may grade into coastal forest or shrublands (including arid saltbushes in the *Chenopodiacae* family).

Function

Sarcocornia quinqueflora.
(Photograph: Simon Bryars)

As well as the plants that epitomise saltmarshes, they are also home to some quite specialised species of animals and other life forms. Animals with interesting adaptations include molluscs(especially pulmonate gastropods), crustaceans (especially burrowing crabs), insects and other arthropods more associated with terrestrial habitats. Occasional visitors include fishes (for feeding at high tide), birds (especially for roosting but also feeding opportunities) and bats.

Algae and microbes are common in saltmarshes, and unvegetated or bare sediment areas known as “salt pans” or “rotten spots” can be common and extensive in semi-arid areas; these may be similar to the sabkha of desert countries.

Saltmarshes provide an ecological service to the human population living on their shores in the form of some protection from storms and coastal erosion and as such need to be conserved as an integral part of SA coasts. It should be noted that, like mangroves, these coastal bioshields cannot provide complete protection; they must be part of regional plans to reduce the human risk, the loss of property and infrastructure and sustain ecological services to an acceptable level.

Saltmarshes can be restored depending on the severity of the natural hazards, the bathymetry, and the climate, the local land use, and the available options to survive extreme events. But it is neither an easy nor assured task, many restoration attempts around the world have only resulted in partial recovery of the character and values of natural saltmarshes. Saltmarshes warrant a place amongst all the coastal resources that the human population living along SA estuaries and coasts value and rely upon for their livelihood and quality of life.

Surprisingly given the importance of saltmarshes, Fairweather (1990), when reviewing the output of Australian marine ecological research through to the 1980s, identified saltmarshes (along with sandy beaches) as the least studied or understood of the major coastal habitats. The number of studies was much less than would be suggested by the prevalence (e.g. extent of coastline or area) of these habitats. That situation has improved to some extent over the last 20 years, to the point where a book summarizing what is known about this habitat in Australia (Saintilan 2009a) was published. Earlier treatments (e.g. Adam 1990) contrasted how little was known about saltmarsh in Australia with the situation in Europe or North America

Threats

As coastal development and use by the expanding population continues, saltmarshes are more likely to be impacted. The human impacts on saltmarshes (often in conjunction with adjacent mangroves) are well discussed in Coleman (1998), Adam (2002), Connolly & Lee (2007), Adam *et al*. (2008), Fotheringham & Coleman (2008) and Saintilan (2009a). Here we list them with some discussion but these references add much further detail to this discussion.

Development and pollution

As for mangroves and other low-lying coastal habitats, early settlers and developers generally considered saltmarshes as wastelands - places to be filled in and put to “better” use after they were “reclaimed”. Thousands of hectares were thus converted to pasture, buried under rubbish tips or used for roads, industrial sites, playing fields, housing, car parks and other developments. The most widespread destruction of saltmarshes has resulted from filling to create dryland sites for coastal land uses by humans. This landfill can modify the local tidal range and thus patterns of inundation in any remnants that persist. Thus much of our remaining saltmarshes are poorly connected to the seas or otherwise suffering from disturbed hydrology. As for mangroves, once the landfilled area is in use, other environmental problems usually follow. Stormwater runoff, accidental spills of pollutants and discharge of treated or untreated effluent cause environmental problems in remnant saltmarshes.

Elevated nutrient levels, from sewage and stormwater discharges, could also affect saltmarsh ecosystems adjacent to outfalls or urbanised centres. Saltmarshes to the north of Adelaide have been used for the production of salt and are often impacted with bund walls to limit tidal inundation. Many of these saltmarshes do not receive anything like the natural degree of infrequent interchange of seawater at high tides. Through a lack of inundation, saltmarsh sediments may suffer from acid sulfate soil syndrome.

Ecological degradation from land uses

Housing projects can destroy large areas of saltmarshes, and straightening of meandering tidal channels causes changed tidal levels and reduced inundation and hence nutrient uptake for the remaining saltmarshes. Saltmarsh ecosystems remove nutrients from runoff as they cover large area that are occasionally flooded and drained by meandering streams that slowly release water to the sea. If these meanders are straightened out, for example for boating channels, the water passes more quickly to the sea and many saltmarshes will not be flooded as frequently with little chance for nutrients and organic matter to be retained and used in the saltmarshes. Bund walls are useful for flood mitigation but their environmental impacts include limiting the upward rise of flooding king tides and so result in disconnection and destruction of habitat in the area beyond the bunds. Hydrodynamic changes to saltmarsh habitats thus have multi-faceted and extreme impacts.

Saltmarsh degradation caused by off-road vehicles.
(Photograph: Ron Sandercock)

In many areas saltmarshes are grazed at levels beyond their natural use by kangaroos. Stock moving along pathways alters drainage lines and these acts as shallow channels that often remove water very quickly from flooded areas. Similar subtle changes to topography resulting in altered drainage also come from use of off-road vehicles or attempts at mosquito control via runnelling. Even a single vehicle pass can produce changes that can last decades, either removing (crushing) vegetation or creating lower paths that alter drainage lines and rates. Such damage can be readily seen across any saltmarsh surface so impacted.

Pest species

A number of weedy species of plants are found in saltmarshes close to urban land or otherwise impacted (e.g. from nutrient-rich runoff). These are few in number of species, however, because most land plants cannot tolerate saturated soils and many aquatic species cannot tolerate hypersaline soils. Invasive species e.g. *Spartina anglica* (being actively but destructively controlled by PIRSA Biosecurity at places like Middle Beach) or *Juncus acutus* are also of concern in some areas of the state. In the eastern states, invasion by mangroves can be an issue, especially in relation to altered sediment budgets from the catchment. In the future, interactions with any mangrove stands that expand under climate change could be a growing threat to saltmarshes.

Climate change

Carbon dioxide assimilation interacts in complex ways with aspects of saltmarsh physiology. Some saltmarsh plants have C4 or CAM metabolic pathways and these may do better under higher temperatures and increased CO_2 levels than C3 plants. Given that saltmarsh plants are already “on the edge” in regards to their water relations, increases in water-use efficiency may not be possible. The general trade off between water use and CO_2 acquisition means the saltmarsh response to high atmospheric CO_2 may not be easy to predict. Also saltmarshes naturally reach their zenith at mid-latitudes (Saintilan 2009b) and so a general rise in temperatures may not favour many species and probably not over the grey mangrove. The most likely effects of sea level rise will be to further squeeze saltmarshes into a narrowing space between the sea and human habitation and other structures. Reports of this “coastal squeeze” phenomenon are already coming from the eastern states (Saintilan 2009b).

Vulnerability

Saltmarshes in South Australia grow in most of our marine bioregions except for Eucla and Otway, but are most common in the bioregions around the Gulfs. Their inherent vulnerability is multiplied because they are squeezed between the sea and human land uses and because the general public knows little of them. Unlike seagrass they are easily seen but were often thought of as a nuisance or a 'wasteland' and a suitable place for local rubbish dumps. As the coast is developed saltmarshes are often in the way and have been removed in some urban places, to be replaced by port facilities or residential or industrial use. Places where saltmarsh has been impacted by human disturbance include Barker Inlet (in relation to bund walls and other disruptions to hydrology); upper Gulfs (in relation to development, infrastructure and off-road vehicle usage); and smaller remnants throughout the state. Maps of South Australian saltmarshes can be seen at www.naturemaps.sa.gov.au.

Considerations for MPAs in South Australia

The uneven distribution of saltmarshes across the marine bioregions and the early but ongoing loss of these low-lying lands since South Australia was settled, suggest that remnant saltmarshes should be protected wherever they still persist. Thus a high level of protection from zoning is suggested for many saltmarsh areas.

South Australia lags behind other states in how much is known about our local saltmarshes, as illustrated by Saintilan (2009a), a multi-authored work covering most taxonomic groups of biota found in saltmarshes as well as pure and applied scientific questions about them: there was no contribution from SA. Local expertise can be found in Doug Fotheringham (of DENR Coastal Management Branch) and Peri Coleman (e.g. Coleman 1998; Fotheringham & Coleman 2008). The size requirement of a viable saltmarsh is unknown but should be considered when zoning or placing protection on them. There is virtually no literature about size dynamics and the faunal communities that live in saltmarsh of different sizes and the viable size of a whole marsh is never discussed.

In other parts of the world saltmarshes are known to be important for various endangered or threatened species and for the goods and services they provide; thus they are protected with varying degrees of success. But saltmarshes always suffer from the perception that they are swamplands that are good for little except growing mosquitoes!

Conclusion and recommendations

Saltmarshes grow along many parts of the coast of South Australia. To determine if human interventions in conservation of saltmarshes is having any effect, detailed mapping and monitoring must be repeated without delay. The earlier maps are not useful in measuring small changes in density, coverage or condition of saltmarshes but the later ones undertaken by DENR that are now part of the Saltmarsh and Mangrove data layer provide much better coverage and at a finer scale.

Monitoring should take the form of detailed mapping, and permanent transects and quadrats be put in place to answer specific questions on the success or otherwise of human intervention including MPAs. Sensitive areas of saltmarsh in marine parks should be zoned to prevent disturbances that will impact on them. A widespread educational program to alert the public to the importance of saltmarsh as feeding areas for fish, protection of the coast, and habitat for birds should be initiated. From this knowledge, more support for zoning and protection of saltmarshes will be gathered.

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Seagrasses

Hugh Kirkman

Description and Distribution

Seagrasses are marine flowering plants adapted from a terrestrial mode of growth to growing in the sea. They have many of the attributes of land plants with substantial underground rhizomes and roots. There are 21 species in nine genera of seagrasses in South Australia if the genera *Ruppia* and *Lepilaena* are included. They grow in shallow sheltered bays from Port McDonnell near the Victorian border to Fowlers Bay in the west.

The two gulfs and many large bays in South Australia are the habitat of vast meadows of seagrass. In the late nineties, the South Australian coast was mapped underwater to a depth where the bottom was visible from satellite or aerial imagery. These maps were at a scale of 1:100,000 and gave an indication where the State's seagrass meadows were (see NatureMaps: http://www.naturemaps.sa.gov.au). There is little or no knowledge of whether these meadows are changing in health or size, although some mapping was subsequently carried out in Gulf St Vincent for the Adelaide Coastal Waters Study. Further mapping has also been undertaken, in collaboration Natural Resources Management Boards across the State.

Seagrass meadow; *Posidonia.*
(Photograph: Simon Bryars)

Function

Seagrasses form some of the most productive ecosystems on earth, rivalling even crops of corn or sugar cane. The beds afford shelter and nursery areas to numerous fish and invertebrates. Seagrass beds are filters to overlying seawater and prevent erosion and accretion of coastlines. They are a nutrient sink and provide a detrital foodweb for many animals and bacteria.

Threats

The human impacts on seagrasses are well discussed in Ralph *et al*. (2007). Here we list them with some discussion, but Ralph *et al*. (2007) adds much to this discussion.

Development

Runoff from land clearing in preparation for housing construction may be the largest impact on offshore seagrass meadows. The problem is that the land is cleared for building and sometimes heavy rains wash off the topsoil because it is no longer held by vegetation. New roads and cuttings for roads are another source of sediment run-off. Development of the coast by building causeways and shoreline armouring may divert water and generally destabilize beaches and shorelines. Rivers are often diverted or changed to enable the extraction of freshwater and this may have an effect on seagrass beds by favouring one species that prefers seawater over another that has adapted to changed salinity conditions.

Physical damage to seagrass beds can occur when marinas, jetties and boat ramps are built on or adjacent to seagrass beds. Alternatively, these structures may change the hydrology (water circulation patterns) of the area, reducing on-shore drift and water flow. Mining and/or oil and gas extraction from under seagrass beds are potentially damaging to seagrass beds when considering freshwater flows, oil spills and mining accidents that cause collapse of mined areas. In the early part of last century fibre from the sediment under *Posidonia australis* in Gulf St Vincent was mined for cellulose use in clothing and explosives (Winterbottom, 1917). The dredging marks are still evident and little *Posidonia* has returned to this region.

Pollution

Human occupation of the coastal zone is accompanied by the dangers of pollution. Industrial chemicals from factories, including heavy metals, petrochemicals and toxic compounds are a danger to seagrass ecosystems. Heavy metals, petrochemicals and nutrients enter the sea from runoff and stormwater drains. Agricultural runoff containing herbicides and insecticides can damage seagrass beds and its associated fauna.

By far the most damaging pollutant to seagrass beds is the release of nutrients. The Adelaide Coastal Waters study showed a loss of about 5,000 ha of seagrass attributed to small amounts of nutrients released into the area from sewage treatment plants (Fox *et al*, 2007). These nutrients promoted epiphyte growth that smothered seagrass. The study demonstrated the vulnerability of *Amphibolis* and *P. sinuosa* to low levels of increased nitrogen. Eutrophication occurs when high nutrient loads, particularly inorganic nitrogen, are taken up by opportunistic macroalgae growing on seagrass leaves. Growth of epiphytic algae blocks light to the seagrass blades, preventing photosynthesis, and eventually smothers the seagrass. The epiphytes and dead seagrass leaves fall to the substrate beneath, are broken down by bacteria that use up oxygen, and this anoxic sediment gives off hydrogen sulphide that kills the benthic flora and the whole seagrass ecosystem may be lost.

Another way that seagrass plants are prevented from photosynthesising is by increasing the turbidity of the surrounding water. As mentioned above, this occurs when runoff containing sediment flows across the seagrass bed. Dredging near seagrass beds increases turbidity and there may be a smothering effect as well if silt screens are not used. If the sediment load is very high, the effect of seagrass leaves slowing the surrounding water will cause the sediment to drop out of the water column and smother plants.

Aquaculture

Sheltered waters, besides being the optimal habitat for seagrasses, make preferable sites for aquaculture, including oyster farms and fish cages. The oyster farms may be on seagrass beds that become damaged by trampling and, as with fish cages or other structures, shading of seagrass plants will cause some decline (Tanner and Bryars, 2006). Aquaculture in Spencer Gulf needs careful management to prevent seagrass damage.

Fishing

The effects of overfishing on seagrass beds can be quite devastating. Although not scientifically proven in South Australia, there is evidence from overseas (Williams and Heck, 2001) that a top-down trophic cascade can occur when the top level predators are removed. The decline in large predators brought about by fishing causes an increase in small fish predators which deplete populations of mollusc and crustacean grazers that keep down epiphyte loads. Increasing epiphytes leads to a gradual loss of seagrass as explained above (Williams and Heck, 2001).

Another threat that should be considered in examining the vulnerability of a seagrass bed is that of inappropriate fishing methods. Seagrass ecosystems are considered vulnerable to some methods of trawling. There is evidence from other parts of Australia and the world that scallop trawling is very damaging to seagrass ecosystems (Fonseca *et al*., 1984; Eleftheriou and Robertson, 1992 and Curie and Parry, 1996 for bare sand) but other trawling for fish or prawns should be closely examined for the damage it may do.

Invasive Species

Invasive species are a problem in seagrass meadows in other parts of the world and of particular note in seagrass beds is the damage done by *Caulerpa taxifolia* in *Posidonia oceanica* beds in the Mediterranean (Meinesz, *et al*., 1993). *C. taxifolia* was found in West Lakes but removed by lowering the salinity in the waterways. There was no success in removing it from the Port River. Some consideration should be given, to other invasive species that may arrive, when considering the vulnerability of seagrass to marine pests (Glasby and Creese, 2007).

Climate change

The full extent of climate change has not yet been demonstrated or predicted in South Australia nor have the forecast extremes eventuated yet. However, loss of seagrass due to exposure to strong sunlight or heat has been shown to damage seagrass beds in South Australia (Seddon *et al*. 2000). Diligent monitoring of seagrass beds will alert managers of disease and poor health of seagrass meadows. Temperature rises greatly exceeding average rates of change over the last 20,000 years are predicted. Climate change affects ocean temperature, salinity, acidification and aragonite saturation, sea level, circulation, productivity and exposure to damaging UV light (Fine and Franklin, 2007).

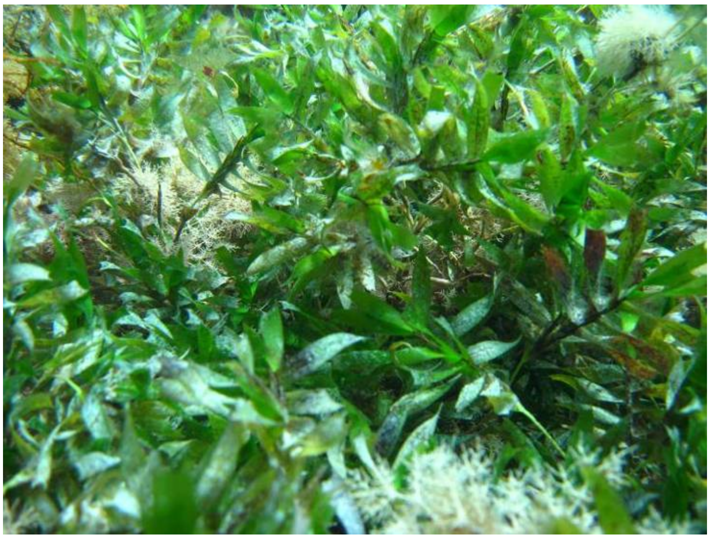
Storms stir up sediment in shallow seas and hence reduce light to seagrass. The light required by seagrass to live in winter is often very low and plants are at a compensation level. Increased storm frequency means that there will be increased turbidity and this may reduce light to lower than compensation levels for marginal meadows at the deeper edge. Increased frequency of storms may also disturb seed beds that normally lie in the sediment, e.g. *Halophila australis* and *ovalis* were lost from Hervey Bay, Queensland when two very large storms followed each other, the first destroying the seagrass and the second destroying newly germinated seedlings (Preen *et al*., 1995). Preen *et al* (1995) also mention that excessive prawn trawling may have exacerbated the storm effect.

Storm intensity may also increase the disturbance to seagrass meadows. It has been estimated that a one in a hundred year storm can remove seagrass from its substrate. Kirkman and Kuo (1990) reported on the formation of blowouts in a *Posidonia sinuosa* bed near Perth and estimated that a one in 60 year storm caused blowouts to this bed. Later a one in a hundred year storm removed *Posidonia coriacea* in Two Peoples Bay near Albany in WA in 1984. There is a photo of the drift rhizomes on the beach after this storm in Kirkman and Kuo (1990). Those beds are not yet completely recovered. Storms, of the intensity that occur once in a hundred years, may increase in frequency to one in forty or fifty years giving *Posidonia* beds, in particular, no chance of recovering.

Warmer temperatures and ice cap melting are expected to raise sea levels. For seagrasses this will bring their habitats shoreward. Those seagrasses growing at the deeper edge of their habitat may be lost while the shallower margins will gain coverage. The problem is if development has used those shallower edges and the seagrass can move no further up the shore, large areas will be lost. Furthermore, those slow growing genera like *Posidonia* may not be able to “catch up” in the shallower sites now suitable for their growth. The building of sea walls, coastal roads, housing to the edge of the sea and other development must be carefully managed with sea level rise in mind.

Little is known about the effect of seawater temperature rising, but shifts in distribution are expected. Seagrass plants cannot move as can some invertebrates and fish as the water temperature increases. The success of a slow distributional shift will depend upon the suitability of a new habitat being available.

As carbon dioxide rises in the atmosphere more is dissolved in seawater leading to ocean acidification. In seagrass ecosystems, calcareous epiphytes will be the main victims. The response of calcareous epibionts to a raise in pH to 7.7 in aquaria was a loss of all calcareous algae and the only calcifers were bryozoans at pH 7.7 (Martin *et al*., 2008). This result may have dramatic effects on biogeochemical cycling of carbon and carbonate in coastal ecosystems dominated by seagrass beds.



Seagrass, *Amphibolis antarctica*, Eyre Peninsula.
(Photograph: DEH)

Vulnerability

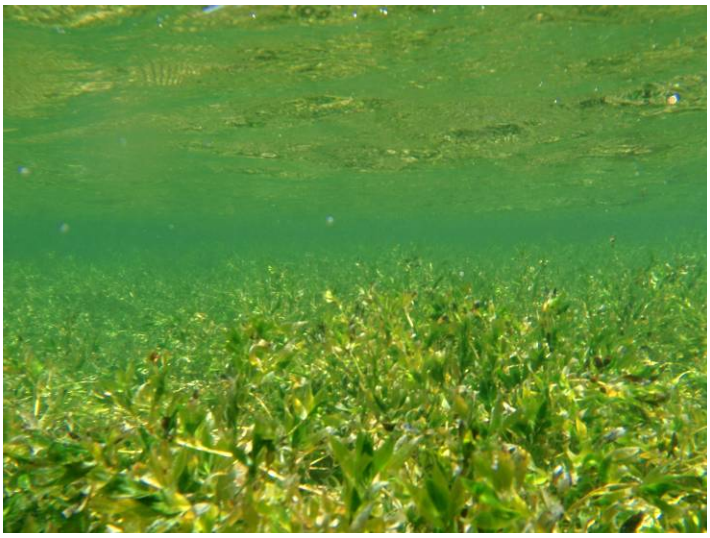
Vulnerability is the susceptibility of an organism or community to a disturbance. Vulnerability depends upon exposure, sensitivity to impacts and the ability or inability to cope or adapt. Seagrasses use relatively high levels of light and grow in shallow nearshore waters making them extremely susceptible to light reduction and to damage by human activity such as pollution and propeller scarring. As the use of the coastal zone grows, so will the damage to seagrass ecosystems unless proactive steps are taken to avoid these impacts. Shipping and the likelihood of accidents and oil or other pollution spills will increase.

It is critical to note that seagrass mortality happens relatively rapidly, whether mechanically induced such as by dredging, or changing the local hydrology, or physiologically induced from reduction in light. Time scales for loss can range from weeks to years. Recruitment, however, does not typically keep pace; yet, if the damaged site is capable of supporting continued cover, some seagrass may recolonise within a few growing seasons. The seagrasses of South Australia are different from each other in many ways and one of these is in their ability to recolonise bare substrate. The genus *Posidonia* may take decades to recover once a bed is lost. The genera *Halophila* and *Zostera* are more rapid colonisers but cannot grow in some of the vigorous water movement areas in which *Amphibolis*, *Posidonia coriacea, P. kirkmaii* or *P. angustifolia* grow. Recovery by natural recruitment is a demographic process with tremendous spatial and temporal variation and is very difficult to predict (Kirkman and Kuo, 1990).

The most easterly bed of *Posidonia* is found at Port MacDonnell, the next eastward location of this species is in Corner Inlet in Victoria or on the north-west coast of Tasmania. Beachport has vulnerable seagrass beds that have already been impacted by boating and development. One of the largest beds in South Australia is at LacepedeBay, this stretches from near The Boulders to Cape Jaffa. This bed is vulnerable because of the farm drains or diverted creeks that drain farmlands in the hinterland. There is also the town of Kingston and development of marinas and boat ramps along this coast. Care should also be taken with dealing with the large beach wrack. Sometimes this has an unpleasant odour or completely covers the recreational beach. This wrack has always been there as far as local people can remember. Its breakdown returns nutrients to the highly productive seagrass bed. Because excess nutrients are being added from runoff from farms in the hinterland, some wrack may be removed for garden mulch without depriving seagrass of nutrients. Wrack is the habitat for many insects, amphipods and terrestrial animals and provides food seasonally to birds and other animals.

In Spencer Gulf the seagrass meadows form extensive areas. From Port Germein to Port Pirie *Posidonia australis* forms enormous beds with corresponding drifts of wrack on the beaches. This area has low water movement and is not subjected to ocean swells so it is vulnerable to land-based sources of pollution which are not readily dissipated. In northern Spencer Gulf reports by Seddon *et al*. (2000) at 33° 31'.0, 137° 53'.5 showed loss of *Amphibolis antarctica* due to exposure to heat and UV light. Such occurrences will continue and may increase with climate change and sea level rise. The sea level rise may cause plants to move shoreward and these colonising communities may be subjected to exposure and be more sensitive as colonising plants. Spencer Gulf was also the site of *Posidonia australis* harvesting at the beginning of the twentieth century. The scars left from this harvesting remain at Port Broughton and are probably of scientific and cultural interest.

On the west coast of Eyre Peninsula consideration should be given to seagrass beds that are in inlets, sheltered bays or remnant estuaries that are ideal sites for aquaculture. Coffin Bay is an example of an area that needs some careful management. Interesting associations between seagrass beds and mangrove are found in Streaky Bay and Smoky Bay and these need further investigations for management and conservation purposes. Fowlers Bay is the last large area of seagrass before the Western Australian border. It has a good representation of many South Australian seagrass species.



Seagrass bed, *Amphibolis antarctica,* NeneValley.
(Photograph: Sarah Bignell)

Considerations for MPAs in South Australia

The size requirement of a viable seagrass bed is unknown. There is nothing in the literature about the viable size of a bed for each different species. There are some seagrass beds in South Australia that need protection and their designation as marine protected areas would enhance the biological diversity and keep possibly unique areas available to stakeholders. Horseshoe Bay at Victor Harbour contains *Heterozostera tasmanica* which, currently, is the only record in the State. In Gulf St Vincent the *P. coriacea* bed at Aldinga Beach stretching to Sellicks Beach is very unusual. It was probably impacted by a one in a hundred year storm, much as the storm in Two Peoples Bay removed rhizomes and whole plants. Now the plants are returning as clumps about five metres across. Another unusual feature is that these clumps grow in about 20 cm of sand then the rhizomes enter a pebble substrate. Towards the southern-most point of Yorke Peninsula, Marion Bay has the largest bed of *P. kirkmani* in the State.

Conclusion

Climate change is a consideration that must be taken seriously yet is of unknown consequences. Consideration should be given to replicate some seagrass meadows within MPAs to cover the possibility of losses when the frequency and intensity of storms increases. The position of inland boundaries should be considered to allow for climate change and subsequent migration of beds shoreward. Providing opportunities for changes in distribution within a park, because climate change has caused species and habitats to move, should be considered.

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Shellfish Beds

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Description and distribution

Shallow-water areas dominated by bivalves (so-called “shellfish beds” or “shellfish reefs”) have been recognised around the world as being at great risk of demise (Beck *et al*. 2009) because of their inherent low resilience and a history of exploitation and/or disturbance from human activities. In particular, oyster reefs have been affected to the point of largely being in “poor condition and at risk of extirpation as functional ecosystems” (Beck *et al*. 2009, p.4), including those in South Australia. Beck *et al*. (2009) claim that oyster reefs are the most imperilled marine habitat on the planet. This is particularly so where native species of bivalves have been heavily utilised but are now in danger of being overrun by feral populations of non-native species (especially the Pacific oyster, *Crassotrea gigas*) that have been introduced to stock oyster industries (Eyre Peninsula being a local case in point, where PIRSA Biosecurity SA now spends considerable money on destroying feral oysters).

In South Australia, we have had several different species of bivalve dominating different sorts of shellfish beds in different places (Table 1). The most notorious example would be the native flat oyster *Ostrea angasi* that was heavily exploited from places like Coffin Bay to the point of commercial extinction by the 1930s (Wallace-Carter 1987), with no wild harvest being possible past about 1945. Rather than once being harvested in many thousands of tonnes each year, it is now rare to encounter more than a few flat oysters on soft-sediments anywhere in the State. The demise of this native species was due to a few factors in combination, including a very heavy harvest regime in the absence of any fisheries science on the species, the reproductive peculiarities of all bivalves (see Threats below), and also the fact that their recovery was limited by the way they were harvested. Unlike most other oysters, *O. angasi* breeds at a different time of year and was dependent upon dead shells of its species and their fragments as settlement substrata. Once the oyster harvest (done largely by raking the sea floor from boats) had collected that shell material and discarded it on land, there was virtually no hard material on the floor of these bays to attract the next generation.

A cluster of adult *Pinna bicolor* showing recent growth at posterior shell margins, and typical epibiota. Predatory seastar *Uniophora granifera* in foreground.
(Photograph: Craig Styan)

South Australia’s most spectacular bivalve is the “razor fish” or fan shell *Pinna bicolor* that can grow to half a metre in size, and was extensively studied by Alan Butler in the 1970s and 1980s (e.g. see Butler & Brewster 1979; Butler & Keough 1981; Butler 1987, 1998, 2008). They live in soft sediments in an upright position with the wider end protruding above the sediment surface. These protruding shells provide some of the only hard substrata available in seagrass beds and soft bottoms in our Gulfs and so have been utilised by a wide array of sponges, ascidians and other sessile invertebrates that also can live on jetty pilings (Kay & Keough 1981; Keough 1984). They also provide the main substratum used by one small species of abalone, *Haliotis cyclobates* (Shepherd 1973), so their role in promoting biodiversity is a clear one.

Table 1: Types and features of shellfish beds relevant to South Australian waters.

Bed type	e.g. species	Depths	Habitats	e.g. places	Vulnerability & threats	References
Razorfish (fan shell) & hammer oyster	*Pinna bicolor* *Atrina tasmanica* *Malleus meridianus*	Subtidal to lower part of intertidal in some places	Soft sediments, relatively sheltered, patchy macrophytes	Gulfs, Chain of Bays	Very slow growing & lifestyle not suited to rapid replacement, susceptible to harvest for food, trawling, dredging, pollution, & other bottom disturbances	Shepherd 1973; Butler & Brewster 1979; Wells & Roberts 1980; Butler & Keough 1981; Ward *et al*. 1986; Butler 1987, 1998, 2008; Styan & Strzelecki 2002; Tanner 2005
Native or flat oyster	*Ostrea angasi*	Shallow subtidal	Sheltered soft bottoms, especially in muddy sediments	Coffin Bay, other west coast bays	Very patchy settlement that relies on its own shell fragments, overfished to commercial extinction by the 1930s	Wallace-Carter 1987; Beck *et al*. 2009
Cockles	Sand – *Donax deltoides, Paphies elongata* Mud - *Katelysia rhytiphora, K. peronii, K.scalarina*	Intertidal Shallow subtidal to intertidal	Sandy open coast beaches Sandy to muddy sediments	Coorong beach Section Bank, Chain of Bays	Very mobile populations Susceptible to digging, harvest	Murray Jones & Ayre 1997; Schlacher *et al*. 2008; Sheppard *et al*. 2009 Cantin 2010
Scallops	*Equichlamys bifrons,* *Mimachlamys asperrimus*	Subtidal	Attached to jetty piles or seagrasses Aggregate on soft sediments	Gulf jetties	Very mobile once disturbed	Styan & Butler 2003; Butler 2008
Mussels	*Mytilus galloprovincialis, Limnoperla (Xenostrobus) pulex, Brachidontes erosus, Austromytilus rostratus, Trichomya hirsutus*	Intertidal to subtidal	Hard substrata (both natural & artificial)	Hard-rock seashores, reefs & jetty pilings in lower Gulfs & open coastline	Layering of beds prevents dislodgement by water movement so integrity is key to resistance, variable recruitment so relies on mast years to replace populations	Turner *et al*. 2006; Edgar 2008

Pinna bicolour also suffers little natural mortality once it reaches a size of a few centimetres long and so its reproductive cycle is keyed to living for two decades or so. They have been harvested for their meat (the adductor muscle is both edible and useful bait) and their upright stance makes them susceptible to any activity that scours the seafloor. Hence Tanner (2005) reported the apparent loss of many extensive beds of this species (along with the unusually-shaped hammer oyster *Malleus meridianus*) from Gulf St Vincent and Investigator Strait over a 30-year interval. They also appear to be absent (Butler 2008) from intertidal depths on the eastern side of Gulf St Vincent but are still present in that shallowest of waters on the western side. In some parts of Gulf St Vincent they are possibly being replaced by the exotic fanworm *Sabella spallanzoides* (Styan & Strzelecki 2002).

Function

Bivalves can only feed by filtering the water (suspension feeders) of particles or straining sediments (deposit feeders) for organic matter. The bivalves that form beds tend to be suspension feeders and their great densities provide an important ecosystem service (along with ascidians, sponges, bryozoans and other sessile invertebrates) of filtering seawater of particulate matter. Beds often appear to be a monoculture of the bivalve after which they are named (Table 1) but they also provide considerable structure for other invertebrates, algae and even juvenile fishes to live on, either attached to their shells or hiding within the matrix of the bed (Peake & Quinn 1993). Thus they are rightly termed ecosystem engineers in that they are important for biodiversity over and above the species of bivalve concerned.

The two- or even three-dimensional dominance of these bivalves in beds often arises from episodic settlement of large numbers of larvae in a gregarious manner that occupies all available space and squeezes out other sessile organisms (including bivalves of other species) as individuals grow in size. The arrival of such large numbers of larvae in any place or any time is inherently variable and so bivalves are notorious for their recruitment variation. The age structure on the shore or in a bed often reflects the legacy of some big year of settlement in the past. The lack of more continual replacement of individuals leads to some susceptibility to conditions that change between years of big recruitment events. Settlement preferences combined with other aspects of their life history (see Threats below) may lead to extreme vulnerability.

Blenny in dead *Pinna* shell, Gulf St Vincent.
(Photograph: Craig Styan)

Threats

As most species are sessile or largely immobile (except for the swimming scallops and surf-zone cockles), bivalves tend to be vulnerable to many disturbances of the seafloor, including dredging, trawling, construction of pipelines, cables or offshore structures, changes to currents and other water flow, etc. A number of species are also harvested for either food or bait and tend to be targeted where available (recreational daily-bag limits exist for fan shells, cockles). They are regularly cleaned off boat bottoms and other structures as part of the undesired fouling assemblage.

One of the big risks with bivalves that are disturbed is that they can have great difficulty re-establishing themselves. This might be because of their needs at the settlement/recruitment stage(s) or because of the way they breed. All bivalves are broadcast fertilisers in that they release eggs and sperm into the water column and then rely upon water movement to bring them together for fertilisation (Styan & Butler 2003; Butler 2008). This means that they need to be close enough together for mixing to occur and hence it is possible for a population to be thinned to the point where they can no longer breed. This tends to mean that reproduction drops off rapidly once this lower threshold of density is reached (called by ecologists the Allee effect), often with little warning that this threshold is being approached as populations dwindle (for whatever reason). It is likely (Butler 2008) that many *Pinna* beds are at this stage now with sparse populations of obvious and old (large) individuals that have no hope of ever reproducing again. Thus the future for these populations, as they reach their limits of longevity or die from anthropogenic causes, appears tragic.

Because of their filter-feeding nutrition, many bivalves accumulate heavy metals and other toxicants from surrounding waters and have been identified as sentinel organisms for monitoring industrial lead pollution in Spencer Gulf (Ward *et al*. 1986). Susceptibility to water quality that is diminished by pollution is another potential cause of declines in historic populations of a number of bivalve species.

Recreational activities like vehicles or even trampling probably also take quite a toll with the intertidal taxa such as *Donax*, *Paphies* or *Katelysia* (Schlacher *et al*. 2008; Sheppard *et al*. 2009), although that has not been measured yet in South Australia. Cockles (*Donax, Katelysia*) are commercially fished and hence managed as a fishery.

Vulnerability

Some shellfish beds are found on hard substrata, e.g. mussel beds on rocky intertidal platforms or subtidal reefs or on artificial structures such as jetty pilings. These are often in wave-swept zones, especially along the open coast, and are therefore quite resistant to wave action and other physical disturbances. There they feature as important habitats for other biodiversity. On some subtidal reefs, mussels have been seen to replace algae, especially where sedimentation or other effects of human activities near Adelaide are seen (Turner *et al*. 2006). In that case, subtidal mussel beds might be seen as an indicator of a degraded situation (see also the Algal Forests paper).

But many of South Australia's more important shellfish beds are found in soft sediments and thus very sheltered waters such as in the Gulfs or the Chain of Bays along the western Eyre Peninsula. In these environments they are used to little water flow and less dynamism than in open-coast environments. Larger species such as *Pinna bicolor, Atrinatasmanica* or *Malleus meridianus* are at great risk because of their conspicuous nature as well as attractiveness for use as food and/or bait and there is a propensity for dredges, nets or anchors to remove them along with any other epifauna living at the sediment surface.

Populations of scallops in the Gulfs and straits seem to be rather more dynamic, although there is some evidence of localised declines (Tanner 2005; Butler 2008) and recent experience in Victoria (where scallop fisheries in Port Phillip Bay have been closed) shows that problems to do with introduced species and effects of fishing can be worrying.

***Chlamys asperrima* (Doughboy scallop) with sponge and various ascidians on a fallen piling, Edithburgh.** (Photograph: Craig Styan)

Considerations for MPAs in South Australia

Given the historical changes that have occurred to our shellfish beds over the past 130 years, their precarious situation globally, the biological realities of being a bivalve, and the exceptional examples seen within South Australian waters, we should be giving a high level of protection to many of these beds. In the Gulfs and most of the enclosed bays, there are shallow soft sediments where shellfish beds could flourish if given the chance. Open beaches would need to have sanctuary zones to protect pipis (*Donax deltoides*) from both harvest and vehicles (Schlacher *et al*. 2008; Sheppard *et al*. 2009). There may be a case for undertaking aided restoration to seed at least some of the areas that currently lack bivalves that historically had much more prominent beds.

Conclusion

South Australia is fortunate in having a diverse range of shellfish beds found across a range of depths, wave energies, bottom types and other environmental gradients within State waters. Given the globally parlous state of oyster reefs and other shellfish beds (Beck *et al*. 2009) and the susceptible nature of the bivalves that form the habitat, it is vital that South Australia protect these unusual and species-rich habitats into the future. As habitats defined by conspicuous and either sessile or largely immobile invertebrate animals that are themselves valued, these habitats should be recognisable and easy to communicate their worth to the public.

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Sponge Habitats

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Description and distribution

Sponge beds are sandy or rocky bottom habitats dominated by erect sponges, sometimes up to 1 m high. *Sponge communities* are habitats dominated by encrusting sponges, and *mixed assemblages* are communities where other fauna and algal flora are often dominant.

Sponges occur mainly in three habitat types:

- on shaded rocky surfaces, such as caves and crevices where light reaching the habitat is low. Here sponge communities are common.
- on deeper rocky or sandy bottom below the photic zone, where light levels are low and water movement is moderate to strong. These are sponge beds.
- on shallow rocky or sandy areas within the photic zone. These are often small and rounded, erect forms that have cyanobacterial symbionts, and usually occur as a minor component of mixed assemblages.

Shaded surfaces

There are almost no studies of the cave fauna in southern Australia, but very extensive studies have been done in the 1970s-80s of the fauna of jetty piles by Butler and his students (see review by Butler 2008). Butler thought that the fauna of jetty piles were a 'window on a larger ecosystem of which they were a part', and the studies showed how many species interacted, some aggressively overgrowing their neighbours, some having "stand-offs", and others forming networks, in which no species is the consistent winner.

Shaded rocky habitats are ubiquitous on rocky coasts, but are usually small and patchy, except on steeply sloping, rocky bottom where they can become more extensive. Hence, on the north coast of Kangaroo Island (KI) and on the cliffs of southern Fleurieu Peninsula and western Eyre Peninsula caves and vertical faces, shaded rocky habitats are numerous. The most notable known cave system is on northern KI at the eastern end of Emu Bay, where caves penetrate up to 8 m under the cliff face.

Jetty pylon of Port Hughes jetty (Yorke Peninsula near Moonta) 4-6m deep. Mixed invertebrates including *Carijoa* sp.
(Photograph: South Australia Museum.)

Low-light sponge beds

Sponge beds, as defined above, are limited to places within the gulfs (mainly reef habitats) of moderate to strong tidal flow and low light conditions. They are comparatively rare in terms of proportional cover of bottom habitats, but are known to occur in:

- the channel entrance to Pelican Lagoon, KI at 5–10 m depth;
- the tide race through the deep glacial valley at the bottom of Backstairs Passage at 50–70 m depth (McGowran & Alley 2008);
- the channel entrance to Cowell Harbour at around10 m depth;
- various isolated reefs at 10 m depth in upper Spencer Gulf, (Shepherd (1983);
- various isolated reefs in Thorny Passage, SW Spencer Gulf;

- deep rocky bottom (50+ m) in the eastern Great Australian Bight (GAB) e.g. as off Flinders Island; and
- Orontes Bank in western Gulf St Vincent, and the numerous reefs at 15-25 m depth on the eastern side of the Gulf from Pt Noarlunga north to at least Semaphore, all with typically 80% or more cover of sponges.

Sponge-*Telesto multiflora* community, upper Spencer Gulf 15 m depth.
(Photograph: Kevin L. Branden)

Sponge beds were once very common in the deeper parts of Spencer Gulf (20+ m), notably on deeper reefs off Wallaroo, and at other sites northward toward Point Lowly (S.A. Shepherd unpublished observations). During the monitoring of catches and by-catch on prawn boats in the early 1970s when chains were attached to prawn nets and dragged over the bottom to clear the 'rubbish', many tonnes of sponges were brought up in the trawls.

Shallow-water sponges in mixed assemblages

Mixed sponge-algal beds occur more commonly in rock/sand habitats with slight-moderate water flow and reduced light. Such areas can be found at 10–20 m depth around offshore islands in the eastern GAB, on the north coast KI, and the rock-sand interface in the lower gulfs. Also in upper Gulf St Vincent, Shepherd & Sprigg (1976) recorded a razor-shell (*Pinna*)-holothurian assemblage from the latitude of Ardrossan northwards to the head of the Gulf covering >500 km^2, where the razor-shells were the substratum for a remarkably rich epifauna of sponges to 0.5 m height. In this assemblage razor-shells "reach densities of 5/m^2 or more, and each shell is a kind of micro-reef supporting a rich epizoic assemblage of small sponges, ascidians and bryozoans" (Shepherd & Sprigg 1976). Mixed sponge-ascidian assemblages are also common on many vertical faces on shaded surfaces referred to above.

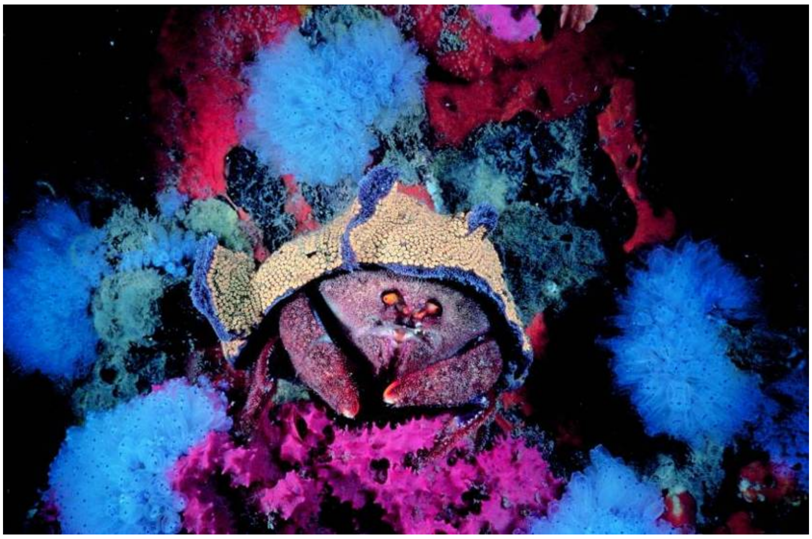
In a study of sponge diversity in the Investigator Group of Islands, S.A., Sorokin *et al*. (2008) recorded 71 species, mainly on transects in algal habitat at ~5 m depth. Many of the species had algal or cyanobacterial symbionts. The study showed a rich diversity of sponges, even though the study omitted the much richer deeper water fauna. For example, more than 480 species were recorded in Recherche Archipelago to ~20 m depth and more than 350 species in the deeper bottom habitats of the GAB marine park (Sorokin *et al*. 2007).

In a second study Sorokin & Currie (2009) undertook a gulf-wide survey of sponges in Spencer Gulf at 120 sites covering the whole of the Gulf as far south as the Gambier Islands. They recorded 105 species of sponge, with high biomass in the southern and northern ends of the Gulf, where little prawn trawling has been carried out. The biomass, abundance and richness of sponges were inversely correlated with prawn trawling effort over the 5-year period preceding the survey, showing that prawn trawling had a severe, negative impact on the Spencer Gulf sponge fauna. This conclusion was supported by the studies of (Currie *et al*. 2009) and Svane *et al*. (2009).

Functional role of sponges

Sponges have an important, but largely unappreciated and little understood, role in benthic systems (see review by Bell 2008). A selection of these are summarised as follows:

- *filtration*: sponges are adapted to extremely low nutrient conditions. They are forced to filter large volumes of water, and to capture the nutrients efficiently. To achieve this efficiency they have a unique adaptation –a high turnover of cells, with massive cell shedding, so that they maintain a constantly renewed filter system (De Goeij *et al*. 2009);
- stabilisation of soft bottom habitats;
- habitat formation i.e. providing shelter for benthic organisms. Sponges support diverse microbial and faunal communities e.g. polychaetes, molluscs, crustaceans etc. Hence they are important in maintaining the biodiversity of reef habitats. In the *Pinna*-holothurian assemblage referred to above, 30 common taxa/taxonomic groups were listed as present (see Table 3, Shepherd & Sprigg (1976);
- *bentho-pelagic coupling*: sponges filter large quantities of water (1–6 litres/hr) and capture picoplankton (<10 µm), DOM (dissolved organic matter), nitrates and food particles, and hence are important in increasing the productivity of bottom habitats. Other studies show that significant amounts of nutrients are transferred to higher trophic levels via sponges;
- *bioremediation*: the high filtering ability of sponges has the potential for natural bioremediation of micro-organism concentrations (e.g. phytoplankton blooms) in the water caused by aquaculture and other causes;
- *facilitation of primary production*: some sponges form associations with cyanobacteria and dinoflagellates, enabling them to assimilate carbon (Cheshire *et al*. 1995);
- *secondary production*: Sponges are eaten by a range of organisms e.g. fish, nudibranchs, crustacean and echinoderms, so are an important part of the food chain;



Sponge crab
(Photograph: Karen Gowlett Homes, SA Museum)

Threats

The major threat to sponge beds in the past has been prawn trawling which has modified or destroyed extensive beds in the two Gulfs. Trawling is now concentrated in deeper areas (more than10 m depth) where the largest sizes of prawns occur and is limited to 40-50 days a year. However, as shown by the recent studies cited above, trawling is still a major threat to surviving sponge beds and sponge-algal/faunal habitats, wherever trawling occurs.

Another threat is sedimentation, which selectively destroys some, but not all, species of sponge. In a study of sedimentation at a site in Western Port, Victoria, Shepherd *et al*. (2008) recorded 66% loss of algal species. In addition many sponge species dominant below 10 m depth also disappeared (J.E. Watson pers. comm.). Other experimental studies (e.g. Gerrodette & Flechsig 1979) have shown that suspended sediments in the water reduce the pumping rates of some tropical sponges. Other studies show that the impacts on tropical sponge assemblages are: reduction in diversity, losses and substitution of species, and a shift to an unstable, less diverse community dominated by encrusting species (Carballo 2006).

Vulnerability

Given the longevity of sponges and their slow recovery from disturbance, all the examples mentioned above (which are in open habitat and on level bottoms) are vulnerable to anchors. Sponge habitats in caves and on vertical faces are less vulnerable to disturbance. However, the most noteworthy of these are those in Backstairs Passage, and the benthic habitats in upper Spencer Gulf, which are believed to be in very good condition.

Considerations for MPAs in South Australia

Wherever possible, benthic habitats with intact sponge beds or assemblages with abundant sponges, as in the numerous examples given above, should be included in habitat protection or sanctuary zones of MPAs. Shaded reef habitats are most common on open coasts, especially offshore islands, where the shore falls steeply into deep water, and also along the steeply sloping north coast of Kangaroo Island. In these places a diversity of habitats and hence a rich diversity of species is usually present, sometimes over a wide depth range. Examples where extensive studies have been undertaken are the Investigator Group, Nuyts Archipelago and the Althorpe Islands. Sanctuary zones around such islands will capture a diversity of habitats and therefore merit the highest form of protection, as recently advocated by Bell *et al*. (2006).

Sponge beds are relatively rare, and from the few studies they appear to have a high diversity. They also play an important role in benthic ecosystems. Wherever possible they merit protection in habitat-protection zones or in sanctuaries.

Conclusion

Sponge habitats tend to occur in low light conditions and in places of moderate to strong water movement. Given the vulnerability of sponge habitats on open bottom to trawling and anchor damage, these especially should be conserved in sanctuary zones or habitat protection zones. Sponge habitats on steeply sloping coasts are less vulnerable, but usually adjacent shallower waters have algal forest habitats, which are highly productive and merit protection in their own right. In these cases the diversity of habitats from shallow to deep water merits protection.

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Subtidal Soft Bottom Habitats

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Description and distribution

The most extensive subtidal habitat in South Australia is sedimentary, particularly soft sediments that range in depth from intertidal beaches to the lower limit of State waters. They range in particle size from coarse sands on exposed coasts to fine muds in and around mangroves. Subtidal soft sediments are extraordinarily rich in species that live in the bottom (infauna) and on the bottom (epifauna) with the majority of the diversity being invertebrates.

Red mullet over sandy bottom with polychaete worm burrows.
(Photograph: Simon Bryars)

The infauna burrow below the sediment surface and include polychaete worms, clams, crabs, prawns, and smaller crustaceans, interstitial organisms that live between the sand grains (forams, copepods), and the tiny fauna, called meiofauna, that include tiny crustaceans, nematodes etc. Yet still smaller than this is the poorly known microfauna of bacteria and protists.

The epifauna live either attached to shell or other firm substrate, rooted in the sediment or are mobile on the bottom. They include ascidians, razor-shells, bryozoans, scallops, sponges, seapens, sea-stars, and crabs. In a survey of Gulf St Vincent and Investigator Strait, Shepherd & Sprigg (1976) described six distinct bottom epifaunal assemblages, including a razor-shell assemblage, an ascidian-scallop assemblage, a bryozoan assemblage, a deep seagrass assemblage, and sponge and hammer oyster assemblages, each of them covering 10s to 100s of square kilometres.

The abundance of the above groups can be extremely high, with polychaete worms, amphipods and tanaid crustaceans the most abundant (e.g. Sergeev *et al*. 1988; Loo & Drabsch 2008). For example, sediment samples from eastern Gulf St Vincent contained on average >2000 polychaete worms, and >2600 crustaceans, molluscs and nematodes per square metre (Loo & Drabsch 2008); even mobile sand contained >2600 organisms per square metre (Sergeev *et al*. 1988). The larger epifauna of soft sediments, e.g. razor-shells, hammer oysters, bryozoans, ascidians and sponges, form the structural base for complex bottom communities, creating significant firm habitats in places where rocky substratum is rare.

In places of strong current and deep sediment, as in parts of Backstairs Passage and upper Spencer Gulf, sand waves up to 2 m high can develop (For example see Figure 9), and these form a unique habitat, with an unusual epifauna adapted to an unstable and highly mobile sediment. The epifauna of sand-wave region in upper Spencer Gulf comprised bryozoans, seapens, and ascidians (Shepherd 1983a).

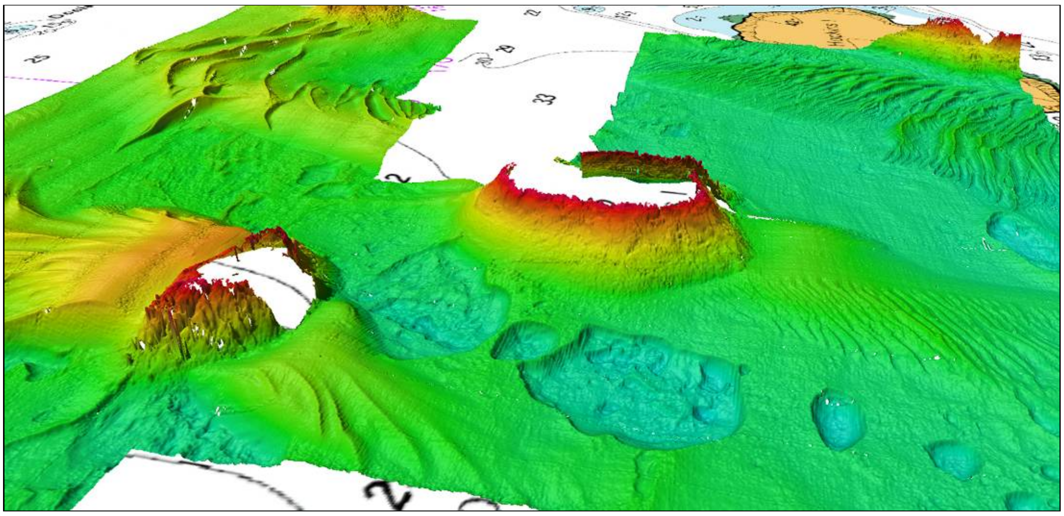

Figure 9. Megaripples near Louis Island in Thorny Passage in Spencer Gulf ~8m ~4m (DENR).

Function

Soft sediment bottoms contain a rich infauna and epifauna, and the epifauna itself provides a substrate and habitat for a rich fauna. The epifauna also capture the productivity of the water column via its filter feeders, and so help retain the primary production of algae, seagrasses and mangroves within coastal waters. Together the benthic fauna provides an abundant food source for many fish and invertebrates, as well as being a nursery for some benthic species.

The organisms on the bottom are critically important as food for higher levels of the food web, as illustrated in (Figure), which shows a simplified food web for Gulf waters. They also provide a refuge and breeding ground for mobile fauna, including fish (snapper and whiting etc) and large invertebrates. These organisms are also highly significant for maintaining stability of the bottom, and for the transfer of productivity of the water column to the benthos.

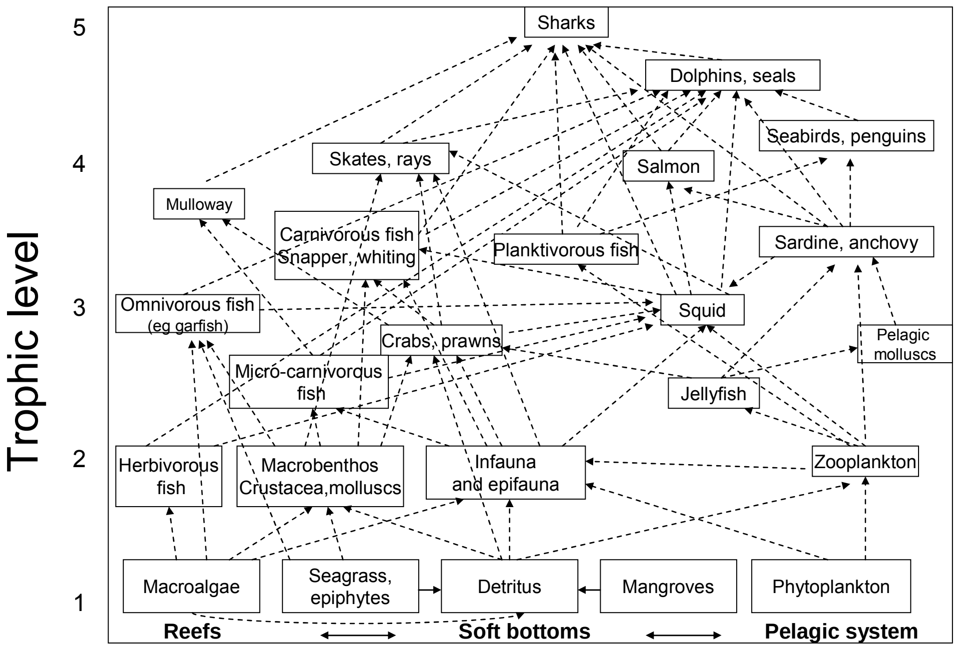

Figure 10. Simplified food web of Gulf St Vincent, showing the contribution of infauna and epifauna to the food of species at higher levels of the food web (from Shepherd *et al*. 2008).

Threats

Soft sediment habitats are vulnerable to any activities that disturb the seabed. These can result from urban and industrial development, and include dredging and dumping, storm-water run-off, sewage and industrial discharges, and trawling. The last activity, trawling, has caused major destructive changes in bottom habitats in both Spencer Gulf and Gulf St Vincent. In Spencer Gulf, Svane *et al*. (2008) described the destruction of epifauna e.g. sponge and hammer oyster beds, and in Gulf St Vincent and Investigator Strait, Tanner (2005) recorded the destruction of hammer oyster beds, bryozoan beds and seagrass (*Heterozostera*) beds over 100s of km^2. Trawling both physically removes fauna, and stirs up sediment which later settles on the bottom and smothers any surviving fauna. In the case of seagrass loss in Investigator Strait, the increased turbidity, together with physical damage, was sufficient to cause its demise.

Vulnerability

Several examples exist in the gulfs of South Australia, in which significant soft bottom communities, occur, and are thought to be unique.
These are:

1. *Razor-fish assemblage*
This habitat occurs in upper Gulf St Vincent at depths of >10 m north of about Black Point toward Port Wakefield over an area of ~250 km^2 (Shepherd & Sprigg 1976). The assemblage is dominated by razor-fish at densities of up to 10 per sq. metre, with abundant epizoic sponges, and a rich fauna on the bottom of echinoderms, hammer oysters, scallops, ascidians and crabs. The assemblage also occurs in upper Spencer Gulf, e.g. near Douglas Bank at depths of 5–15 m and at densities of up to10 per sq. metre (Shepherd 1983b). Elsewhere in upper Spencer Gulf razor-fish are common but at lower densities..
2. *Hammer oyster beds*
Beds of hammer oysters, once common in lower Gulf St Vincent, have disappeared due to prawn trawling (Tanner 2005), but still occur sometimes as isolated reefs in western upper Spencer Gulf, e.g. inshore from Middle Bank at a depth of 10–16 m and at densities of ~10 per sq. metre (Shepherd 1983b). Globally this kind of reef is considered a threatened habitat.
3. *Ascidian-soft coral-bryozoan assemblage*
Throughout upper Spencer Gulf rare ascidians (e.g. *Sycozoa pedunculata*), rare soft corals and gorgonians with tropical affinities (e.g. *Virgularia mirabilis, Telesto multiflora, Echinogorgia* sp., *Scytalium* sp.) occur as well as a number of other rare species of flatworm, nudibranch, and brittle-star (Shepherd 1983).
4. *Bryozoan assemblages*
Extensive bryozoan assemblages occurred in Gulf St Vincent, at depths of 15 m or more, but have largely disappeared as a result of prawn trawling (Tanner 2005). However, remnants may persist off Black Point in the upper Gulf, and also in deeper water in Investigator Strait at depths of 27–35 m in places of strong current where the rare button bryozoan, *Lunulites* sp. and the more common *Parmularia* are dominant (Shepherd & Sprigg 1976).

Orange seapen.
(Photograph: David Muirhead)

Considerations for MPAs in South Australia

The unique assemblages of soft-bottom fauna described above in the upper Gulfs seem to have been preserved where prawn trawling has historically been excluded. Given the sensitivity of such assemblages to any kind of trawling, they should all be included in habitat-protection or sanctuary zones within the MPA network.

Conclusion

Soft bottom assemblages, notably within the Gulfs, contain a rich infauna and epifauna, and are functionally of great importance as they capture the productivity of the Gulfs and transfer it to the benthos. The benthos supports crustaceans of high economic significance e.g. prawns, blue swimmer crabs, and sand crabs, and also provide food for many exploited fish species e.g. whiting, snapper etc (Figure).In addition, many rare species are present in these habitats and need to be conserved. It is important therefore to conserve examples in the MPA network.

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Upwellings

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Definition/Description

The term **upwelling** refers to the rising of cool bottom water from the ocean depths towards the sea surface. **Uplift** refers to cold water rising towards, but not reaching, the surface (Rochford 1991). Sometimes, in an upwelling region, when the driving mechanism weakens, uplift, but not upwelling, will occur. Upwellings and uplift are largely due to simple Ekman dynamics—a steady wind stress causes a net transport of surface water 90° to the left of the wind direction. If the wind-stress is alongshore with the coast on the right, then surface waters are driven offshore, and deeper water upwells on the coast. However, some strong upwellings occur off western Eyre Peninsula without upwelling favourable winds, suggesting that upwellings here may result from intense anticyclonic gyres on the continental shelf (Griffin *et al.* 1997). Upwelled water can be transported 20-40 km a day at speeds of 0.2-0.4 m s^{-1}, and supply pools of nutrient-rich water to coastal areas.

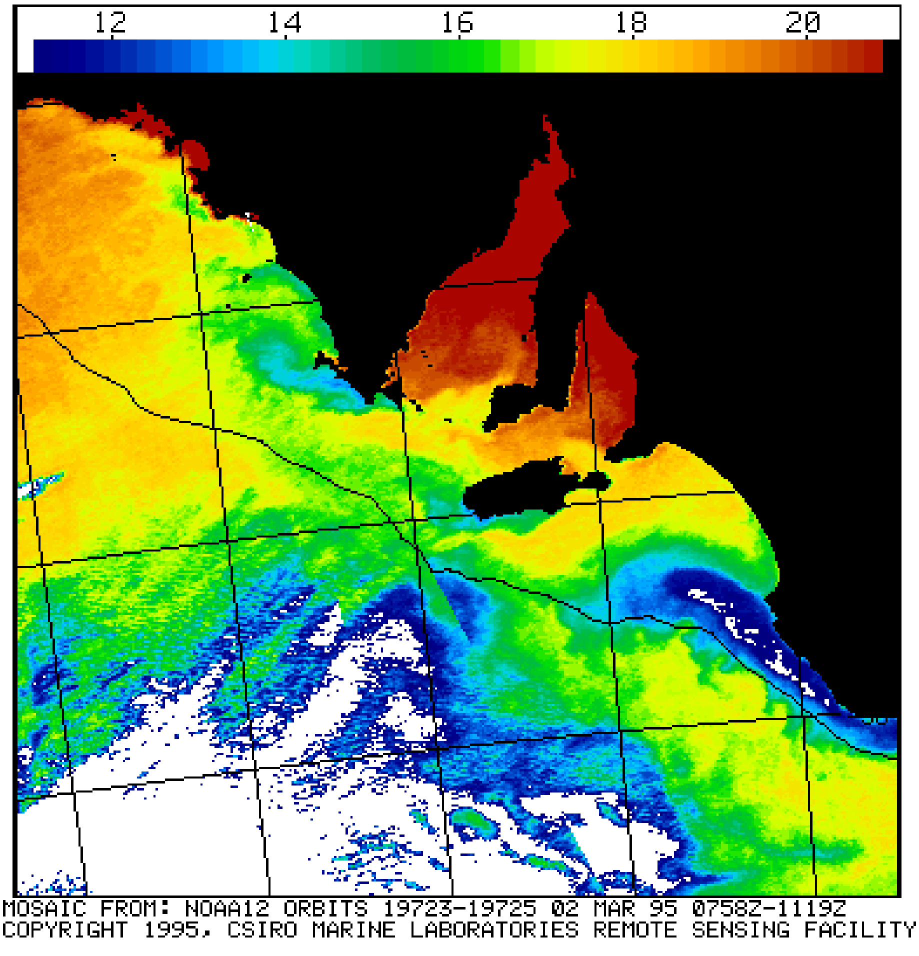

Figure 11.Satellite image showing sea surface temperatures in late summer (March) off South Australia. Colour-coded sea temperature key is at the top. Note the strong upwelling off the Bonney coast, and weaker upwelling in the eastern Bight, extending up to Streaky Bay.

Distribution

Off SE and central South Australia, the strong SE winds, which typically blow for 3–10 days at a time, and 2-4 times each summer, lead to strong upwellings off Eyre Peninsula, western Kangaroo I. and the Bonney coast (Figure 1.). The cold water (11 – 12°C) upwellings onto the shelf extend from Portland, Victoria along the Bonney coast and Lacepede Shelf, into the eastern Great Australian Bight (GAB), and cold water uplift extends onto the shelf as far NW as Cape Adieu near the head of the Bight (Herzfeld & Tomczak 1999; van Ruth *et al*. 2010)(Figure). On the Bonney coast, cold water upwells on to the shelf from 250 m deep and flows into inshore waters and toward the NW (reviews by Kaempf *et al*. 2004; Middleton &Bye 2007). Off southern KI cold water upwells from 150 m deep and much of this cold, upwelled water from the KI pool is transported to the eastern GAB where it flows to the NW (McClatchie *et al*. 2006). However, another possible source of this nutrient-rich, cold water is deep water upwelled from the shelf break, driven by the strong longshore shelf currents of ~50 cm s^{-1} (Herzfeld & Tomczak 1999).

Upwelling Variability

Studies by Kaempf *et al*. (2002) over a decade showed that substantial variability in upwelling intensity occurs between years and over longer time periods. Long-term switches in high- and low-pressure regions in the central Pacific, called ENSO (*El Niño*-Southern Oscillation) have a strong effect. During an *El Niño* year, the Leeuwin Current on the west and southern coast of Australia weakens (Li & Clarke 2004), and winter-time shelf-edge currents are weaker. But off the Bonney coast in SE South Australia and further west to the eastern Bight *El Niño* events lead to enhanced upwelling. More specifically, winter time downwelling during the onset of an *El Niño* is reduced, and in the following summer upwelling is increased, leading to sea temperatures of up to 2°C lower than years with average upwelling (Middleton *et al*. (2006). During *La Niña* (opposite of *El Niño*) events upwelling intensity is markedly reduced. Overall sea temperatures during extreme upwelling events fall ~5°C below the temperature immediately preceding the upwelling.

Spatial variability in upwelling especially in the eastern Bight also occurs due to the unique circulation of upwelling waters on the shelf, and the wide continental shelf. Productivity is very low in some offshore parts of the eastern Bight, but very high in 'hotspots' in the east influenced most by the upwelled water mass (van Ruth *et al*. 2010). Examples of these 'hotspots' are: Cape Adieu; around the Investigator Group of islands; around the bottom of Eyre Peninsula, from Avoid Bay east to Cape Catastrophe and northwards into Thorny Passage; and off western KI. The productivity of these hotspots matches that of the richest known globally i.e. the Benguella and Humboldt Currents; however the hotspots also vary in time and only two of them are conspicuous in (Figure), although others may still be present in sub-surface waters.

Function

Consequences of upwellings

Upwellings bring influxes of nutrients from deep water into the sunlit zone. Consequently, upwelling regions are the most productive areas in the world's seas, and those off South Australia are the most productive in Australia, extending for ~800 km along the coast. The upwelling triggers a series of events. Closest to the upwelling area, phytoplankton production peaks within 7 days of the start of the upwelling, followed by a peak in zooplankton production in the upwelling plume.

Major zooplankton groups are mysids and, more importantly, krill (*Nyctiphanes australis*), both small crustaceans up to 20 mm length. Krill live for ~1 year, and are sexually mature at 3 months. During the day swarms of krill feed on or above the bottom, and rise at night where they swim and feed in shoals. The krill's swarming ability is notable and vast schools covering up to 1 ha in area and in densities of up to 1 million m^{-3} have been recorded in SE Australia (Butler *et al*. 2002).

As discussed in the Pelagic habitats chapter, during the summer Bonney upwelling pygmy blue whales aggregate off SE South Australia and south of Eyre Peninsula to feed on the swarms of krill. In the Jan.–April season, when they are present, up to 25–30 whales are seen during aerial surveys, usually in the depth range 100–200 m, in each of the above two regions. Feeding can occur at all depths according to the depth of krill swarms, and each whale (weighing up to 150 t) can consume 3–4% of its body weight daily (Gill and Morrice 2003; Gill *et al*. 2011). However, there are many other small predators of krill, including the short-tailed shearwater, little penguin, and fairy prion. The major fish predators are 'bait fish' – sardines and anchovies – which occur in vast populations off Eyre Peninsula estimated to often exceed 50 000 t live weight. In the SE Great Australian Bight they support Australia's largest fishery. These in turn attract and support the (now depleted) southern bluefin tuna populations (Ward *et al*. 2006). Other fish predators are jack mackerel and tiger flathead, and invertebrates are squid, lobster and the giant crab (Butler *et al*. 2002); these support trawl, long-line, drop-line and squid-jig fisheries, as well as the lobster and giant crab fisheries. Butler *et al*. (2002) also record the presence in the upwelling region of 17 other species of sea-birds, marine mammals, and fish, listed under the federal *Environmental Protection and Biodiversity Conservation Act 2008* as endangered or vulnerable. If it were not for the seasonal injection of nutrients into coastal waters during upwellings, S.A.'s coastal waters would be impoverished, and productivity extremely low.

Threats

Upwelling regions are determined by the geography of the coastline, and by weather events, and hence are not vulnerable to threats, except those arising from climate change (see below). However, habitats and species can be greatly affected by variability in the intensity of upwellings. A weak upwelling, for example, may adversely affect giant kelp, *Macrocystis*, populations along the coast of SE South Australia (see Section on the *Macrocystis* habitat). Another example is the seriously declining rock lobster fishery in South Australia (Linnane *et al*. 2010 a, b, c). Although the causes are unclear, climatic effects, such as increased upwelling strength from climate change, as well as overfishing appear to be implicated.

Vulnerability

Climate Change

Major climatic trends in southern Australia are reviewed by Wernberg *et al*. (2009). Climate change models predict that westerly winds will weaken to 50°S, and, in the region from the eastern Great Australian Bight to western Victoria, SE winds will be stronger, with an increasing intensity and frequency of *El Niños*, and with fewer but stronger *La Niñas*. The frequency of *El Niño* has been increasing in the last 30 years, and the 2010–11 *La Niña* is the strongest on record, consistent with the above predictions. Stronger *El Niños* will tend to strengthen upwellings, and keep oceanic waters cooler, perhaps mitigating somewhat the general predicted long-term temperature increase of 1–2°C on southern coasts.

Considerations for MPAs in South Australia

Key recommendations of the report by Wernberg *et al*. (2009) include the setting up of long-term monitoring systems to document changes in species, assemblages and ecosystems. Establishment of a network of marine protected areas, and a monitoring program within them, are essential to this endeavour.

Conclusion

The productivity of South Australian waters is wholly dependent on the seasonal upwelling of nutrient-rich, sub-antarctic waters, which in turn is dependent on south-easterly wind strength and the orientation of the coast. The upwelling provides nutrients for phytoplankton and macro-algal production; phytoplankton and algae provide food for zooplankton and many benthic animals; and zooplankton in turn feeds an array of fish species, ranging in size from bait-fish to blue whales.

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